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F-16 ESCAPE SYSTEM COMPUTER SUPPORT

FINAL REPORT

CDRL ITEM #A004

Task Order No. 22

Contract N02262-75-C-0001

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NAVY AND NAVAL AIR FORCE CENTER  
WASHINGTON, D.C.

September 1977

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Prepared for

NAVAL AIR DEVELOPMENT CENTER

Warminster, Pennsylvania

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## F-18 ESCAPE SYSTEM COMPUTER SUPPORT

### FINAL REPORT

#### 1.0 INTRODUCTION

The following report documents the work completed by Computer Sciences Corporation (CSC) under Task Order Number 22, Contract N62269-75-C-0001 for the Crew Systems Department at the Naval Air Development Center (NADC), Warminster, Pennsylvania. This report documents the modifications and additions that were made to an existing emergency egress, pilot ejection from an aircraft, simulation model. The original model, nicknamed ICARUS by the originators, was developed and implemented in FORTRAN on a CDC 6600 computer by the Aeroballistics Division of the Naval Weapons Laboratory (NWL) located in Dahlgren, Virginia.

Documentation of the original version of ICARUS is covered under NWL Technical Report Number TR-3098, dated February, 1974 and titled: 'Air Crew Automated Escape System Simulation Model' and NWL Technical Note TN-K-7-7/74 dated February, 1974 and titled: 'Program Maintenance Manual for ICARUS A Computer Program to Simulate Escape Systems.'

The original model was developed to simulate the ejection seat system of the AV-8A (Harrier) aircraft. The ejection system was designed and manufactured by the STENCEL Corporation. The model was constructed and programmed in a modular form, thus enabling the current or future users of the model to modify or insert new modules into the model in order to adapt the model to hardware changes to the original ejection system or different ejection systems.

The basic structure of the model can be considered as follows:

- Model Control Section - This section controls the overall model data initialization, the individual case study data initialization, requests for aircraft and the seat ejection normal trajectory computations, trajectory data output, adjustments to the trajectory time step (deltat) and case or problem termination.



- Positional or Time Event Activation/Deactivation Section - This section, called by the above section after each step of the trajectory computation, keeps track of each of the position and time event's status during the trajectory. When an event occurrence has been detected by this section, the section initiates a request to have a message outputted indicating that the particular event has taken place, the time of occurrence to be computed and outputted along with the appropriate trajectory data computed at that time. This section is also responsible for the dynamic scheduling of the various equations of motion to be evaluated at each phase of the trajectory computation.

The first request from the NADC Crew Systems Department was that CSC change the output format of the model (ICARUS) from a paragraph to a tabular format. A series of new reports were designed displaying the trajectory data in tabular form (up to nine components per page) with appropriate page and title headings. The input routine was modified to read-in, immediately after the case label card, an output display selection card. The input routine was further modified to interpret the data read-in from this card and to set program transfer switches within the program to cause the printing or inhabiting of the printing, of the data or reports selected by the user via this card. This card enabled the user of the model to select either the original, new or both report formats to be generated and displayed. If the new report format mode of output data display is selected by the user, the ability to select specific reports contained within the mode was also provided via this card. Simultaneously, the original input routine was segmented into smaller routines and the user of the model was given the option (also via the above card) of selecting which input data segment was to be displayed and whether the recovery chute data and plot data is to be outputted.

CSC was then asked to modify ICARUS to compute and display the pilot's dynamic response index (DRI), a measure of the pilot's spinal compression. A spring-damper system is used as a model of the pilot's spine during the ejection

phase. The DRI is computed as a function of the vertical acceleration imposed on the man during this phase. The computation was implemented in the model and a new report was designed to display this data at each time step of the ejection phase. This accomplished, CSC was then asked by Crew Systems to modify the model to take into account the displacement of the pilot's center of gravity during the ejection phase (from catapult ignition to seat/man separation). The displacement of the pilot's center of gravity was modelled by Crew Systems using spring damper equations (one for each direction of motion). These equations were inserted into the model, evaluated and the appropriate vectors were updated to reflect the displacement of the pilot's center of gravity from its original (static) position. A new output report displaying the displacement, acceleration and force components in each direction of motion, was designed and implemented in the model.

The preceeding modifications to the model are considered common to all ejection systems. The following modifications have been implemented in the model in order to adapt and use the model to simulate a different ejection system namely, the Martin-Baker.

The Martin-Baker catapult was modelled by Crew Systems using spring-damper and tube extension equations. The rail interaction with the seat slippers was modelled using spring equations to simulate and determine the friction and normal forces and moments generated along each axis as the slippers move up the rails during the catapult phase. The forces and moments acting on the seat/man combination due to the bending of the tube while extending were modelled using tube bending equations. The above equations were interfaced and implemented in the model. Additional reports displaying the slipper and tube bending position, force and moment data were designed and implemented in ICARUS.

The model was then modified to simulate the Martin-Baker seat back rocket, drogue and recovery chute sequencing logic.

Three new decimal data input sections were added to the model allowing the user of the model to input, via the model's normal input data procedures, the parameters to the dynamic center of gravity, the Martin-Baker catapult and phasing equations.

The following sections (not necessarily in chronological order of implementation) describe in detail the mathematical modelling, timing and sequencing logic, the input/output changes and additions to the model, a description of the new routines that were implemented and interfaced with the rest of the model, macro and detailed flow diagrams of the model, a definition of the new input variables and how to enter them, guidelines as to how to go about implementing the new input variables, and finally how to run the model.

## 2.0 MATHEMATICAL MODELLING CHANGES AND ADDITIONS

### 2.1 Dynamic Response Index (DRI)

A measure of the compressibility of the pilot's spine during the ejection phase of the trajectory has been implemented and interfaced in ICARUS. The pilot's spine is modelled as a mechanical system, a spring-damper. The index of compressibility (DRI) of the man's spine is determined at each time step of the phase as a function of the vertical acceleration (in G's) imposed on the seat/man combination and the resulting displacement value obtained from the spring equation during this phase. Subroutine DERIV has been modified to call a new subroutine titled 'DRICALC' during the ejection phase. Subroutine DRICALC evaluates the spring-damper equation using the velocity and position data obtained after each numerical integration iteration. The dynamic response index is then computed using the displacement value obtained from the integration.

Reference Appendix A for a mathematical presentation of the equations used to determine the DRI.



## 2.2 Dynamic Center of Gravity

The original model was modified to take into account the displacement of the pilot's center of gravity during the ejection phase of the trajectory, from catapult ignition to seat/man separation. The displacement of the man's center of gravity is simulated during this phase by three independent second-order differential equations of motion (spring-damper equations) one for each direction of motion. The equations are numerically integrated at each time step as a function of the resultant axial acceleration imposed on the seat/man combination - yielding the corresponding velocity and displacement components of the man's center of gravity from its static position. The seat/man center of gravity is then recomputed and the appropriate vectors from/to this new position are then updated in the seat/man coordinate system.

The user of the model has been given the option of forcing the model to compute the displacement of the man's center of gravity or ignoring this displacement as was originally done in the model. This option is controlled by the user of the model setting the fifth word of the integer input data array to an integer one if the displacement of the man's center of gravity from its static position is to be computed, a zero or blank entry will force the model to by-pass this computation.

Subroutine DERIV has been modified to call a new subroutine titled 'DYNCG' during the ejection phase. Subroutine DYNCG calls another new subroutine titled 'KUTTA' which performs the numerical integration of the dynamic center of gravity equations, obtaining velocity and displacement components which are then used to evaluate the equations. After the evaluation is completed, DYNCG calls another new subroutine titled 'TRANSFM' which updates the vectors from/to the new seat/man center of gravity location. See Section 4.3 for instructions on how to invoke or inhibit the dynamic center of gravity computation. See Appendix B for a mathematical presentation of the dynamic center of gravity equations.



### 2.3 Martin-Baker Rail and Tube Bending Equations

The ICARUS seat ejection model has been modified to simulate either the Stencil or the Martin-Baker seat ejection system. The user of the model can select which seat is to be simulated by setting the value of the input decimal variable, 'STNCEL' to a zero (0.0) if the Stencil system is to be simulated or to a decimal one (1.0) if the Martin-Baker system is to be simulated. The variable STNCEL is contained in the decimal portion of the Default data file and its value may be altered by the user of the model via the normal Card Input file procedures.

#### 2.3.1 Rail and Tube Bending Equations

The Martin-Baker catapult system has been modelled using spring-damper and tube bending equations to simulate the forces and moments acting on the seat/man during the catapult phase of the trajectory.

Subroutine SEATMAN has been modified to interpret the value of input variable STNCEL to ascertain what seat is being simulated by the model. If STNCEL equals 1.0 and the model is in the catapult phase of the trajectory - subroutine SLIPFMB is called. This new subroutine contains the Martin-Baker catapult equations of motion. These equations (the rail and tube bending) are evaluated and the forces and moments acting on the seat/man combination due to the rail interaction with the slippers and tube bending are determined as a function of the velocity and displacements resulting from the slippers and tube bending motions.

If on the other hand, STNCEL is input as a zero or blank and the model is in the catapult phase of the trajectory, subroutine SLIDFM is called and the forces and moments attributable to the Stencil catapult will be computed.

### 2.4 Martin-Baker Timing and Sequencing

Subroutines EXECUT and STATUS have been modified to interpret the input decimal value of variable STNCEL to ascertain which seat ejection system

is being simulated by the model. As previously mentioned in Section 2.3.1 if the value entered into variable STNCEL is 0.0, the Stencel seat ejection system will be simulated by the model, if the location contains the value of 1.0, the Martin-Baker system will be simulated.

In the Martin-Baker mode of simulation, subroutine STATUS has been modified to check, at each time step of the trajectory, if the catapult tubes 1 and 2 have extended beyond the value specified by input variable SBRON contained in the decimal data segment of the Default data file. If the tubes have extended past this value, the time ( $\pm$  some delta) when the tube length equalled the value specified by the SBRON variable is ascertained. The values of the trajectory variables at this time are computed and displayed and the seat back rocket phase is initiated.

Subroutine INIT has been modified to compute the time of drogue projection (TDP) as a function of the decimal input variables time of catapult ignition (TCI) and the time required to elapse (TMLAP1) before the drogue chute can be projected,  $TDP = TCI + TMLAP1$ .

Subroutines STATUS and EXECUTE have been modified to update or hold constant at each time step of the trajectory an internal clock. This clock has a value of zero initially and updating of the clock commences at TCI. The clock is updated under the following conditions:

if the seat/man altitude  $< ALT1$

or

$ALT1 \leq \text{seat/man altitude} \leq ALT2$  and  $ACC_Z < TIM2GZ$

then the clock is updated - the integration time step is added to the clock location ( $TIMER2 = TIMER2 + DELTAT$ ).

$ALT1$ ,  $ALT2$ ,  $TIM2GZ$ , and  $TMLAP2$  are input via either the Default data file or the Card Input file.

When the internal simulation clock attains the value of  $TMLAP2$ , the recovery chute pack is opened and the recovery chute riser line commences coming out.

### 3.0 PROGRAMMING CHANGES

#### 3.1 Input/Output Modifications

##### 3.1.1 Segmentation of Input Routine

The original ICARUS subroutine INPUT which reads-in the aerodynamic, tabular, decimal and integer data has been segmented into the following ten subroutines: ACT, CONVT, DEFAULT, ENDCASE, INPUT, PTDFLT, TABCONL, TABCRDS, UPDEC and UPINTG. The control routine, subroutine INPUT, computes and at case termination outputs the case execution time, reads-in the case title and user input/output option cards and displays them on the case output listing. The routine then calls subroutine DEFAULT which reads-in the decimal and integer data from the Default file. DEFAULT calls subroutine CONVT which converts the decimal data input as feet or radians to inches or degrees. DEFAULT reads-in the next record contained on the Card Input file and then transfers program control back to subroutine INPUT. Depending on the values of QFLAG read from the Card Input file, subroutines PTDFLT, UPDEC, UPINTG and ENDCASE are called. Subroutines UPDEC and UPINTG reads-in from the Card Input file updates to the decimal and integer data.

Subroutine PTDFLT transfers to the user's output file the updated decimal and integer default data. PTDFLT then calls subroutine TABCONL which controls the reading-in and output of the aerodynamic and tabular data via subroutines ACT and TABCRDS. Subroutine ACT, reads and outputs the aerodynamic data contained on file AERO. Subroutine TABCRDS reads and outputs the tabular data contained on the Card Input file. Before transferring program control back to subroutine INPUT, PTDFLT calls subroutine CONVT which converts the decimal data back to feet or degrees.

Finally, subroutine ENDCASE is called by INPUT and a check is made within this subroutine to ensure that all input data required to execute the case has been read.

### 3.1.2 Additions to the Decimal Data

Three additional input sections have been implemented in ICARUS, Sections 12, 13 and 14. ICARUS' input and output routines have been modified to read the data contained in these sections, from the Default and Card Input files and to display this information along with the other decimal data. Section 12 contains the input parameters to the dynamic center of gravity equations, Section 13 the parameters of the Martin-Baker catapult equations and Section 14 the parameters to the Martin-Baker timing and sequencing logic. For a detailed definition of the variables contained in the above new sections see Section 4.1.2 of this report.

### 3.1.3 Input/Output User Print Options

An additional input card has been added to the Card Input file. This card must immediately follow the case label card. The card has been added to the model input card stream to allow the user of the model to select which input data and output reports are to be transferred to the user's output file for subsequent printing. See Section 4.1.1 of this report for a detailed explanation of how this card is used to control the input/output data display.

### 3.1.4 Additional Output Subroutines, Reports and Plot File

#### 3.1.4.1 Tabular Displays

At the request of Crew Systems, ICARUS' output format was changed from a paragraph format to a tabular format display. A series of new reports were designed displaying the data in tabular form (up to nine components per page) with appropriate page and column headings. To accomplish this, three new subroutines (FETCH, NREP, and REP1) have been implemented and interfaced with ICARUS' input and output routines. Subroutine PROUT has been modified to call subroutine REP1 when integer variable IPROP, read-in from the user's input/output options card, has a value other than zero, indicating that the user has selected at least one of the new output reports to be generated and displayed. Subroutine REP1 interrogates phase indicator variables and based upon the pre-



sent phase of the trajectory a transfer within the routine is made to the appropriate Fortran subroutine call statement to subroutine FETCH. The parameters of the call statement indicate the new reports that can be considered for output in this phase.

Subroutine FETCH ascertains which of the new reports that are logically possible to output at this time have actually been selected by the user to be displayed. The values of the trajectory data displayed in the user selected reports are then passed, one report at a time, to subroutine NREP which formats and transfers the line of data to the associated report tableau for subsequent output.

#### 3.1.4.2 Plot File

An additional new subroutine, CUTTAPE, has been interfaced and implemented in ICARUS. This routine is called by subroutine FETCH. The purpose of subroutine CUTTAPE is to format and output, to a plot file at each step of the trajectory, seat/man positional, rate and angular data. The plot file generated by CUTTAPE is then read by a separate Fortran/PLOT10 program via the Tektronix terminal. The plots of the data generated by this program are copied using the Tektronix hard copying attachment.

### 3.2 Position Event Time Determination

Subroutine HIT controls the determination of the exact time (within a given tolerance) in the trajectory that a specified position value has been obtained, e.g., the instant in time when the catapult tube has extended its full length implying seat/man separation from the Martin-Baker catapult. After the exact time of the event has been determined and output by a call to subroutine PROUT along with the associated values of the variables at that time, HIT has been modified to set NTRY equal to 4 and to call RKSDEQ. Entry into subroutine RKSDEQ with NTRY equal to 4 forces the routine to by-pass the updating of the work array which contains the values of integration variables at time  $t_i$ ,  $t_{i-1}$ , and  $t_{i-2}$ . Thus the values of the variables at time  $t_i$  upon entry into the routine are not retained. The routine then performs the integration over the interval from the event time back to

the time when the event was detected as occurring.

Program control is returned to HIT which then calls PROUT forcing the output of the new values of the variables at the time of the event detection. HIT has been modified to update the Lagrange array YSAL with the new values of the variables obtained from the above integration. In addition, HIT has been modified (Martin-Baker seat only) to compute the seat back rocket burnout time immediately after it has determined the time of seat back rocket ignition.

### 3.3 Simplification of RKSDEQ Coding

The overall coding of subroutine RKSDEQ (the main numerical integrating routine) has been simplified and an additional transfer point was added to the routine. When the routine is called with NTRY set to 4, the updating of the work array before integration is not accomplished and the values of the current time variables are not retained.

### 3.4 Interfacing of the Martin-Baker Time and Sequencing in Subroutine STATUS

Subroutine STATUS has been modified to take into account the anomalies that exist between the Stencil and the Martin-Baker event determination. See Section 2.4 of this report for a detailed explanation of the modifications made to STATUS.

### 3.5 Documentation of New Subroutines

The following new subroutines have been implemented in ICARUS:

ACT	ENDCASE	RKSDEQ (modified and recorded)
CENGRAV	FETCH	RUNGE
CONVT	IDEBUG	PTDFLT
CUTTAPE	INPUT	SLIPFMB
DANGLE	KUTTA	STORE
DEFAULT	NREP	TABCONL
DRICALC	RECALL	TABCRDS
DYNCG	REPI	TRANSM

## UPDEC

## UPINTG

Section 4.3 of this report contains the detailed flow charts of these new subroutines.

3.5.1 Subroutine ACT, called by TABCONL, reads and outputs the aerodynamic data contained on file AERO. The output of the aerodynamic coefficients may be inhibited by the user of the model via the input/output options card.

3.5.2 Subroutine CENGRAV, called by DYNCG, evaluates the equations of motion (spring equations) used to determine the displacement of the pilot's center of gravity from its static position during the seat/man portion of the ejection trajectory.

3.5.3 Subroutine CONVT is called by DEFAULT and PTDFLT. Based upon the values contained in the locations of the formal parameters passed, CONVT will convert the decimal data represented in feet and radians to inches and degrees or vice versa.

3.5.4 Subroutine CUTTAPE generates a file containing data to be plotted. At present the following data is output:

( $X_S$ ,  $Y_S$ ,  $Z_S$ ) - position of the seat/man in (EFCS)

( $M_S$ ,  $V_S$ ,  $W_S$ ) - velocity of the seat/man in (SMCS)

( $\psi$ ,  $\theta$ ,  $\phi$ ) - yaw, pitch and roll angles of seat/man

( $\dot{\psi}$ ,  $\dot{\theta}$ ,  $\dot{\phi}$ ) - yaw, pitch and roll angular rates of seat/man

( $X_{\text{accel}}$ ,  $Y_{\text{accel}}$ ,  $Z_{\text{accel}}$ ) - acceleration of seat/man in (SMCS)

3.5.5 Subroutine DANGLE, called by SEATMAN, computes the derivatives of the yaw, pitch and roll angles ( $\psi$ ,  $\theta$ ,  $\phi$ ).

3.5.6 Subroutine DEFAULT, called by INPUT, reads-in the decimal and integer data from the Default file.

3.5.7 Subroutine DRICALC called by subroutine DERIV evaluates the equation of motion (spring damper) used to determine the index of compressibility of the man's spine during the seat/man phase of the ejection trajectory.

3.5.8 Subroutine DYNCG called by subroutine DERIV computes the new location of the man's and the seat/man's center of gravity as a function of the displacement computed in CENGRAV during the seat/man portion of the trajectory.

3.5.9 Subroutine ENDCASE called by INPUT checks to see that all input data required to execute the case has been read-in.

3.5.10 Subroutine FETCH called by subroutine REP1 ascertains which of the new reports that can be generated and output during this phase have actually been selected by the user to be output. The user selected reports are then further processed, one at a time, to determine which of the variables contained in the report are to be output during this phase, and pointers are set to the core locations where the variables have been stored during this phase. This information is then passed to subroutine NREP which transfers the line of data to the associated report output file.

3.5.11 Subroutine IDEBUG produces reports that are not normally required to be displayed. These reports are used as aides in debugging the model or to help in the analysis of a given simulation test case.

See Section 4.2.3 of this report for instructions as to how to envoke these reports.

3.5.12 Subroutine INPUT called by EXECUT computes and outputs the case execution time at the termination of each case, reads the case title, user's Input/Output Options card, and outputs these two cards as part of the users data listing. INPUT then calls subroutine ACT, DEFAULT, ENDCASE, PTDFLT, TABCONL, UPDEC, and UPINTG. These routines read and output the aerodynamic, tabular, default and card input data files, and insure that all data required to execute the problem case have been read.



3.5.13 Subroutine KUTTA called by DYNCG is the fourth order Gill's variation of the Runge-Kutta numerical integration algorithm. This routine is used to integrate the dynamic center of gravity equations.

3.5.14 Subroutine NREP called by subroutines FETCH and INPUT formats and transfers the line of data passed to it by either subroutine FETCH or INPUT, to the output file designated to display the data.

3.5.15 Subroutine RECALL called by subroutine RKSDEQ replaces the  $t_i$  values of seat/man center of gravity position, rate data, seat/man vectors, Martin-Baker catapult, dynamic response index, and the derivatives for the dynamic center of gravity and dynamic response equations with their corresponding values at  $t_{i-1}$ . These values are then used to determine the exact time an event has taken place.

3.5.16 Subroutine REP1 is called by subroutine PROUT when the new report format has been selected by the user to display output data. Subroutine REP1 interrogates phase indicator variables and based upon the phase of the trajectory subroutine FETCH is called with a formal parameter string indicating which of the new reports may be output during this phase.

3.5.17 Subroutine RKSDEQ called by subroutines CKTME, CKVARB, EXECUT and STATUS has been modified to by-pass the updating of the work array when entered with NTRY set to 4. The overall coding of the routine has been simplified.

3.5.18 Subroutine RUNGE called by subroutine DRICALC numerically integrates the dynamic reflex index equation. The numerical technique used is a Runge-Kutta forth order method.

3.5.19 Subroutine PTDFLT, called by subroutine INPUT, prints the default data. PTDFLT then calls subroutine TABCONL which controls the reading-in and outputting of the aerodynamic and tabular data via subroutines ACT and TABCRDS.

3.5.20 Subroutine SLIPFMB, called by subroutine SEATMAN during the Martin-Baker catapult phase, computes the forces and moments of the seat/man

due to the rail interaction with the seat slippers and catapult tube bending.

3.5.21 Subroutine STORE called by subroutine INIT and RKSDEQ saves the values at time  $t_i$  of the: seat/man center of gravity position and rate data, Martin-Baker catapult data, DRI data, and the derivatives of the dynamic center of gravity and reflex index, after each integration.

3.5.22 Subroutine TABCONL called by subroutine PTDFLT controls the reading of the aerodynamic and tabular data via subroutines ACT and TABCRDS.

3.5.23 Subroutine TABCARDS called by subroutine TABCONL reads the tabular data from the Card Input file and transfers the data to the output file.

3.5.24 Subroutine TRANSFM called by subroutine DYNCG updates the vectors from/to the seat/man center of gravity during the ejection phase of the trajectory.

3.5.25 Subroutine UPDEC called by subroutine INPUT reads from the Card Input file updates to the decimal data.

3.5.26 Subroutine UPINTG called by subroutine INPUT reads from the Card Input file updates to the integer data.

Section VI-3 of this report contains detailed flow diagrams of the above new routines.

#### 4.0 USER INPUT DATA INSTRUCTIONS

##### 4.1 Definition of Input Variables

##### 4.1.1 Definition of User's Input/Output Options Card Format (6I2, 3X, 35I1).

Subroutine INPUT has been modified to read-in an additional input card. This card is mandatory and must immediately follow the case title card. The card contains the following user coded output display switch settings:

<u>Card Col.</u>	<u>Col. Name</u>	
2	IPROP	<p>A zero or blank entry will force the program to display output variables in original ICARUS format.</p> <p>A '1' keypunched in this column will force the program to display output variables in the new report format, Reports 2-23</p> <p>A '2' keypunched in this column will force the program to display output variables in both the original and new formats.</p>
4	IPLOT	<p>A zero or blank entry in column 4 of the card will inhibit the generation of the file.</p> <p>A '1' keypunched in column 4 of the card will force the program to generate a file containing data to be plotted.</p>
6	IRECH	<p>A zero or blank entry in column 6 of the card will inhibit the outputting of the recovery chute angle and reference area.</p> <p>A '1' keypunched in column 6 of the card will force the program to display the recovery chute angle of attack and reference area after each iteration.</p>
8	IAERO	<p>A zero or blank entry in column 8 of the card will inhibit the outputting of the seat/man aerodynamic data.</p> <p>A '1' keypunched in column 8 of the card will force the program to output the aerodynamic data.</p>
10	IDFLT	<p>A zero or blank entry in column 10 of the card will inhibit the outputting of the default data.</p> <p>A '1' keypunched in column 10 of the card will force the program to output the default data.</p>
12	ITABP	<p>A zero or blank entry in column 12 of the card will inhibit the outputting of the tabular data.</p>

A '1' keypunched in column 12 of the card will force the program to output the tabular data.

<u>Card</u> <u>Cols.</u>	<u>Col.</u> <u>Name</u>	
16, 17, 18, ... 35	IRSW (1, 2 ... 23)	A '0' or blank entry in these columns will force the program to inhibit the printing of corresponding new reports (Reports: 1, 2, 3 23).

A '1' keypunched in these columns will force the program to print the corresponding new reports (Reports: 1, 2, 3 ... 23).

Presently, reports 2 to 23 have been defined and implemented. Subroutines ICARUS, INPUT, PROUT and RECOV have been modified and three new subroutines (FETCH, NREP, REP1) have been added to the model to interpret the above inputted switch settings and to generate the user requested output reports.

#### 4.1.2 Definition of the New Decimal Data Sections

The following three additional input sections have been added to the decimal data segment of the Default file:

##### 4.1.2.1 Section 12, Dynamic Center of Gravity

Section 12 contains the following 12 input parameters to the dynamic center of gravity equations:

CX	XSLACK	SXP
SXN	CY	SY
CZ	ZSLACK	SZP
ZBOT	SZN1	SZN2

Where: CX, CY, and CZ are the damping constants in the X, Y and Z directions respectively, expressed in units of per-second.

SXP, SXN spring modulus constants in the X direction, expressed in units of per-second<sup>2</sup>.



XSLACK	dead zone in X direction ( $0 < X \leq XSLACK$ ) where the frictional acceleration term (FX) is set to zero.
SY	spring modulus constant in the Y direction, expressed in units of per second <sup>2</sup> .
SZP, SZN1, and SZN2	spring modulus constants in the Z direction, expressed in units of per second <sup>2</sup> .
ZBOT	bottoming distance in the Z direction, expressed in feet.
ZSLACK	upward slack in the Z direction ( $0 \leq Z \leq ZSLACK$ ) where the frictional acceleration term (FZ) is set to zero, expressed in feet.

above. Reference Appendix B for a mathematical presentation of the

#### 4.1.2.2 Section 13, Martin-Baker Catapult

Section 13 contains the following 26 input parameters to the rail and tube bending equations plus the program control switch STNCEL indicating which ejection seat system is to be simulated by the model (STNCEL set to 0.0 implies the Stencil system, set to 1.0 implies the Martin-Baker system):

XKSLIP	ZKSLIP	XCSLIP
ZCSLIP	UMSLIP	XYKTOR
XYCTOR	YKTUB	PKTUB
RKTUB	YCTUB	PCTUB
RCTUB	UMTUB	TUBLT1
TUBLT2	TUBLT3	ELMOD
DIAMI1	DIAMO1	DIAMI2
DIAMO2	XCTCP	YCTCP
ZCTCP	STNCEL	RAILNT

Where: XKSLIP, ZKSLIP are the spring modulus constants in the X and Z directions of the rail/slipper equations in units of /sec <sup>2</sup>.

XCSLIP, ZCSLIP	are the damping constants in the X and Z directions of the rail/slipper equations in units of /sec.
UMSLIP	coefficient of friction used in rail/slipper equations (Y direction).
XYKTOR	rail/slipper torsional spring modulus constant in the pitch plane (X-Y) in units of (ft-lbs/rad).
XYCTOR	rail/slipper torsional spring-damper constant in the pitch plane (X-Y) in units of (ft-lbs - sec/rad).
YKTUB, PKTUB, RKTUB	catapult torsional spring modulus constants in the yaw, pitch and roll direction in units of (ft-lbs/rad).
YCTUB, PCTUB, RCTUB	catapult torsional spring damper constants in the yaw, pitch and roll directions in units of (ft-lbs-sec/rad).
UMTUB	catapult coefficient of friction in Y direction.
TUBLT1, TUBLT2, TUBLT3	length of tubes 1, 2 and 3 respectively in feet.
DIAMI1, DIAMI2	inside diameters of tubes 1 and 2 respectively in feet.
DIAMO1, DIAMO2	outside diameters of tubes 1 and 2 respectively in feet.
XCTCP, YCTCP, ZCTCP	coordinates of the seat contact point with catapult tube in feet (CCS).
RAILNT	length of slipper rails in feet.

See Appendix C for a mathematical presentation of the use of the above variables.

#### 4.1.2.3 Section 14, Martin-Baker Phasing

Section 14 contains the following 7 input parameters to the Martin-Baker drogue chute, seat back rocket ignition, recovery chute and seat/man separation simulation:

TMLAP1	TMLAP2	ALT2
ALT1	TIM2GZ	SMSEPF
SBRON		

Where:	TMLAP1	is the time (from catapult ignition) of drogue projection for the Martin-Baker system.
	TMLAP2	is the time that the recovery chute clock must advance to, from a zero initial value, before the Martin-Baker recovery chute pack will open.
	ALT1	altitude below which the recovery chute clock is updated automatically until TMLAP2 is reached (in feet).
	ALT2	if seat/man are above this altitude, the recovery chute clock is not updated.
	TIM2GZ	vertical acceleration (in G's) which will stop the clock from being updated if the man's altitude is below ALT2 and above ALT1 and his vertical acceleration is greater than TIM2GZ.
	SMSEPF	resultant force that the recovery chute must exert (greater than or equal to) on seat/man to cause the man to separate from the seat, in units of lbs.
	SBRON	distance seat must travel up the catapult tube before the seat back rocket will ignite, in feet.

Changes to the decimal data, defined above for Sections 12, 13 and 14, can be accomplished at run-time via the normal Card Input procedures, i.e., entering in the decimal data section of the file: the variable name(s) (columns 2-7)

28-33 and 54-59), and corresponding values (columns 8-27, 34-53, and 60-79).

Reference Section 3 of NWL Technical Note TN-K 7/74 dated February 1974.

#### 4.1.3 Definitions of the New Integer Data Variables

The second segment of the Default data file contains the integer input data to the model. The first word of this segment contains the count (30) of the number of integer data values that immediately follow. The next two records contain the integer values to be read-in under a 16I5 format. The first four words of the 30 word array were used by the original implementors of the model. The remaining 26 locations were set aside for future use.

In the revised version of ICARUS 5 of the 26 extra words, words 5 through 9 of the 30 word integer array INT, have been used as follows:

<u>Word</u>	<u>Card Columns</u>	
5	21-25	Set by user of the model to control the computation of the dynamic center of gravity. 0 - entered in this word (via the Default file only) will force the model to bypass the dynamic center of gravity computation. 1 - entered in this word will force the model to compute the dynamic center of gravity.
6	26-30	Set by the user of the model to request additional output reports not normally displayed - model debugging or case analysis aides. Entering, via the Default file only, the following values into these words will force the model to generate the following reports: 1 - Prints all forces and moments on seat/man. 2 - Prints values contained in locations NTRY, NUMEQS, DELTAT, DELTARP, WORK (1-5).
7	31-35	
8	36-40	



- 3 - Prints forces and moments due to catapult.
- 4 - Prints Martin-Baker catapult displacements and rates.
- 5 - Prints the Quaternions.
- 6 - Prints CTLWDS common block.

9

41-45

Set by the user of the model to control the generation of the Tektronix plot file.

- 0 - entered in this word will inhibit the generation of this file.
- 1 - entered will force the model to generate the file.

#### 4.2

#### Program Load, Execute, Output and Load Map Procedures

##### 4.2.1

CALL, PRLD - this procedure loads the ICARUS program and associated data files and executes the program.

#### KRONOS PROCEDURE PRLD:

```

00110 ASSIGN,MS,OUTPUT.
00111 REWIND,OUTPUT,TAPE11,TAPE12,TAPE13,TAPE14,TAPE15,TAPE16,TAPE17.
00112 REWIND,TAPE18,TAPE19,TAPE20,TAPE21,TAPE22,TAPE23,TAPE24,TAPE25.
00113 REWIND,TAPE26,TAPE27,TAPE28,TAPE29,TAPE30,TAPE31,TAPE32,TAPE33.
00114 REWIND,TAPE34,TAPE35,TAPE36,TAPE37,TAPE38,TAPE39,TAPE40,TAPE41.
00115 REWIND,TAPE42,TAPE43,TAPE44,TAPE45.
00120 GET,TAPE1=DFDATA.
00130 GET,CARDIN.
00140 GET,TAPE2=AERO.
00150 GET,NEW.
00155 GET,COMCLIR/UN=SYSTEM.
00160 GET,MATLIB/UN=SYSTEM.
00163 RFL,127777.
00170 LDSET,LIB=MATLIB.
00171 LDSET,LIB=COMCLIR.
00180 LOAD,NEW.
00190 EXECUTE,ICARUS,CARDIN.
00200 EXIT.

```

##### 4.2.2

CALL, TAPOUT - this procedure copies the new report files onto the output file.

KRONOS PROCEDURE TAPOUT:

REWIND,TAPE11,TAPE12,TAPE13,TAPE14,TAPE15,TAPE16,TAPE17,TAPE18,TAPE19.  
REWIND,TAPE21,TAPE22,TAPE23,TAPE24,TAPE25,TAPE26,TAPE27,TAPE28,TAPE29.  
REWIND, TAPE20,TAPE30,TAPE31,TAPE32,TAPE33.  
REWIND,TAPE34,TAPE35,TAPE36,TAPE37,TAPE38,TAPE39,TAPE40,TAPE41.  
REWIND,TAPE42,TAPE43,TAPE44,TAPE45.

COPYBF,TAPE11.

COPYBF,TAPE12.

COPYBF,TAPE13.

COPYBF,TAPE14.

COPYBF,TAPE15.

COPYBF,TAPE16.

COPYBF,TAPE17.

COPYBF,TAPE33.

COPYBF,TAPE30.

COPYBF,TAPE31.

COPYBF,TAPE32.

COPYBF,TAPE18.

COPYBF,TAPE19.

COPYBF,TAPE20.

COPYBF,TAPE21.

COPYBF,TAPE22.

COPYBF,TAPE23.

COPYBF,TAPE24.

COPYBF,TAPE25.

COPYBF,TAPE26.

COPYBF,TAPE27.

COPYBF,TAPE28.

COPYBF,TAPE29.

COPYBF,TAPE34.

COPYBF,TAPE35.

COPYBF,TAPE36.

COPYBF,TAPE37.

COPYBF,TAPE38.

COPYBF,TAPE39.

COPYBF,TAPE40.

COPYBF,TAPE41.

COPYBF,TAPE42.

COPYBF,TAPE43.

COPYBF,TAPE44.

COPYBF,TAPE45.

4.2.3            CALL, MAP - this procedure loads the ICARUS program and associated data files and generates a full load and subroutine cross reference map of the program.

KRONOS PROCEDURE MAP:

```
GET,TAPE1=DFDATA.  
GET,COMCLIB/UN=SYSTEM.  
GET,CARDIN.  
GET,TAPE2=AERO.  
GET,NEW.  
GET,MATLIB/UN=SYSTEM.  
RFL,127777.  
ASSIGN,MS,OUTPUT.  
LDSET,LIB=MATLIB,MAP=SBEX.  
LDSET,LIB=COMCLIB.  
LOAD,NEW,MATLIB.  
NOGO.  
DISPOSE,OUTPUT=PR/E1=CD8002.
```

5.0            HOW TO INSERT NEW DATA AND NEW REPORTS

5.1            Additions to the Default Decimal Data (Segment One of the File)

Whenever additional decimal input parameters are required by the model, i.e., extensions to the model such as the dynamic center of gravity equations, a new data section can be appended to the last section (currently Section 14) by:

- Changing the first record (one word in length, I5 format) of the Default data file (DFDATA) to reflect the number of additional decimal words to be input. Currently this word contains the integer value of 253. If a new section were to be added con-

taining six additional variables, the word count would be increased to 259. The values of the six new variables to be read-in would be inserted immediately after the 253rd word (words 254, 255, ... 259) in a 3E20.14 format.

- Subroutines INPUT, INIT, PTDFLT, UPDEC, DEFAULT and the appropriate labelled common blocks, dimension and integer array must be updated to reflect the additional variables.

The 253 (current) decimal data values are displayed on the user's output file in the 14 data sections as follows:

<u>Section</u>	<u>Begin Word</u>	<u>End Word</u>	<u>Length</u>	
1	1	12	12	Angular data
2	13	85	73	Positional data
3	86	97	12	A/C data
4	98	103	6	(Seat back rocket angles)
5	104	108	5	Slider block
6	109	111	3	Dart
7	112	145	34	S/M inertia, weights, area
8	146	163	18	Chute data
9	164	174	11	Chute data
10	175	183	9	Event time date
11	184	207	24	Event time steps
12	208	219	12	Dynamic C. G.
13	220	246	27	M. B. catapult
14	247	253	7	M. B. phasing

## 5.2 Additions to the Default Integer Data (Segment 2 of the File)

The first record after the decimal data, 1 word in length (I5-format) indicates the number of integer words that immediately follow. Currently this count is set at 30. The next two records contain the integer data values in a 16



I5 format. The first 4 words of the 30 word integer array have been formally defined by the original implementors of the model and have been equivalenced to the following integer data names: ISMA, ISTOP, ISMS and ISEAT respectively. see pp. - 63, 71, 72 of the Program Maintenance Manual (Reference 2) for a detailed definition of their use in the model.

The first 4 integer data inputs may be updated via the Card Input file. The remaining 26 words have not been formally defined for updating using the Card Input file procedure. The 26 words can currently only be modified by changing their values in the Default file. Words 5 to 9 are currently being used for plotting, program case analysis and debug purposes.

See Section 4.1.3 of this report for further details regarding their use in the model.

### 5.3 Implementation of New Reports

The first card immediately after the case title card is the user INPUT/OUTPUT Display option card. This card contains 35 switches (one for each report) of which 23 are currently in use. These switches are set by the user to control the printing or non-printing of each of the 35 reports. If a new report is to be added, switches 24 to 35 are available to be assigned to the report. Report page and column headings can be entered by inserting the appropriate page and column headings in the data statement array allocated in subroutine NREP. Subroutines REP1 and FETCH must be updated to call the new reports with formal parameters pointing to the data locations to be printed and the format to be used in displaying the locations.

6.0 ICARUS FLOW DIAGRAMS

6.1 Macro Structure of ICARUS

Control Section

Overall model data initialization.

Case study data initialization.

A/C and seat/man requests for trajectory computations and output.

Adjustments to the trajectory time steps.

Termination of case studies.



Event Control

Monitors the status of position and time events.

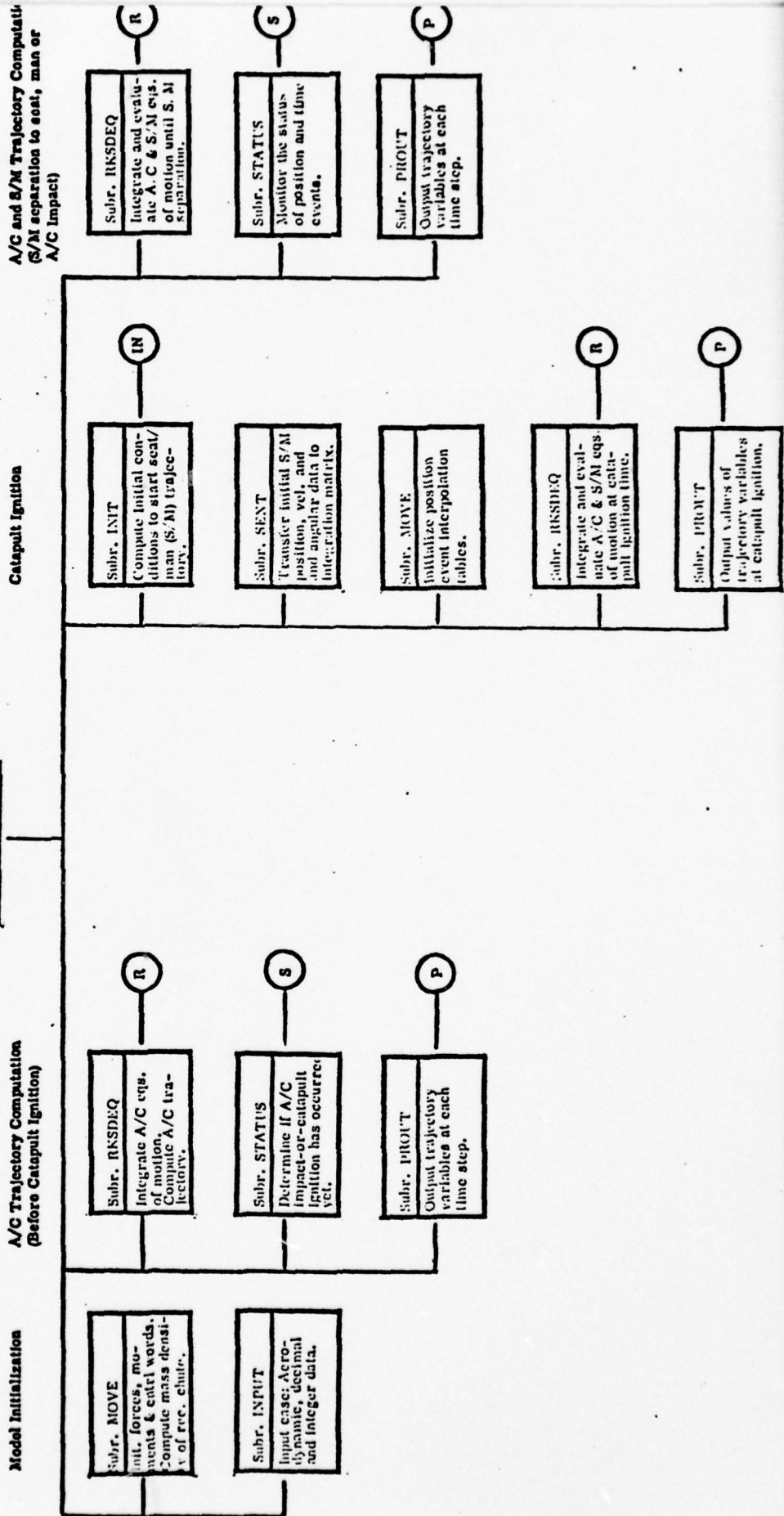
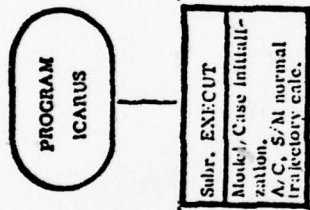
Initiates output request for message indicating a particular event has occurred.

Initiates requests for the determination of the exact time that an event has occurred and to output this time and the values of the trajectory variables at that time.

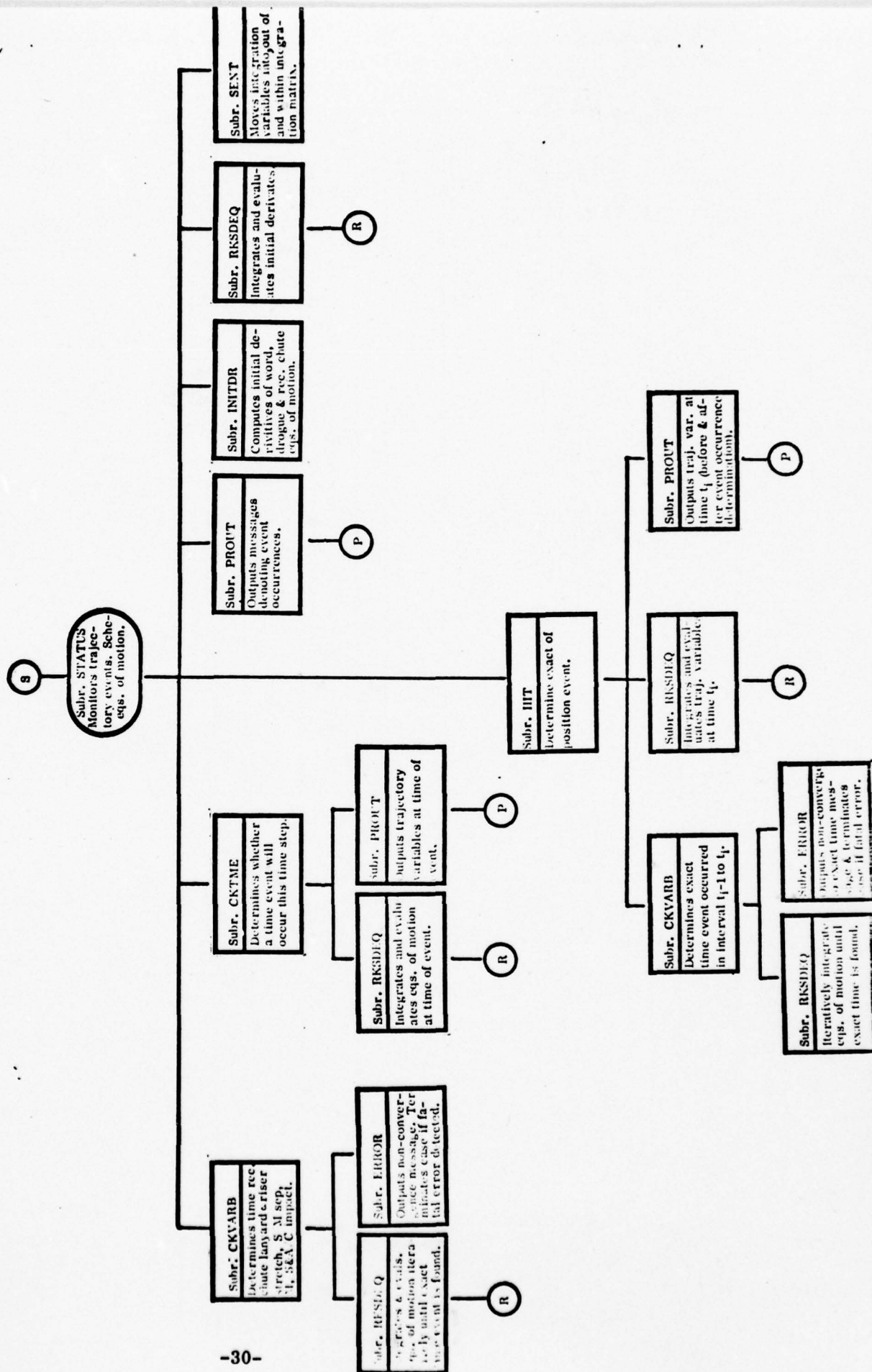
Dynamic scheduling and initialization of the equations of motion to be evaluated at each phase of the trajectory.

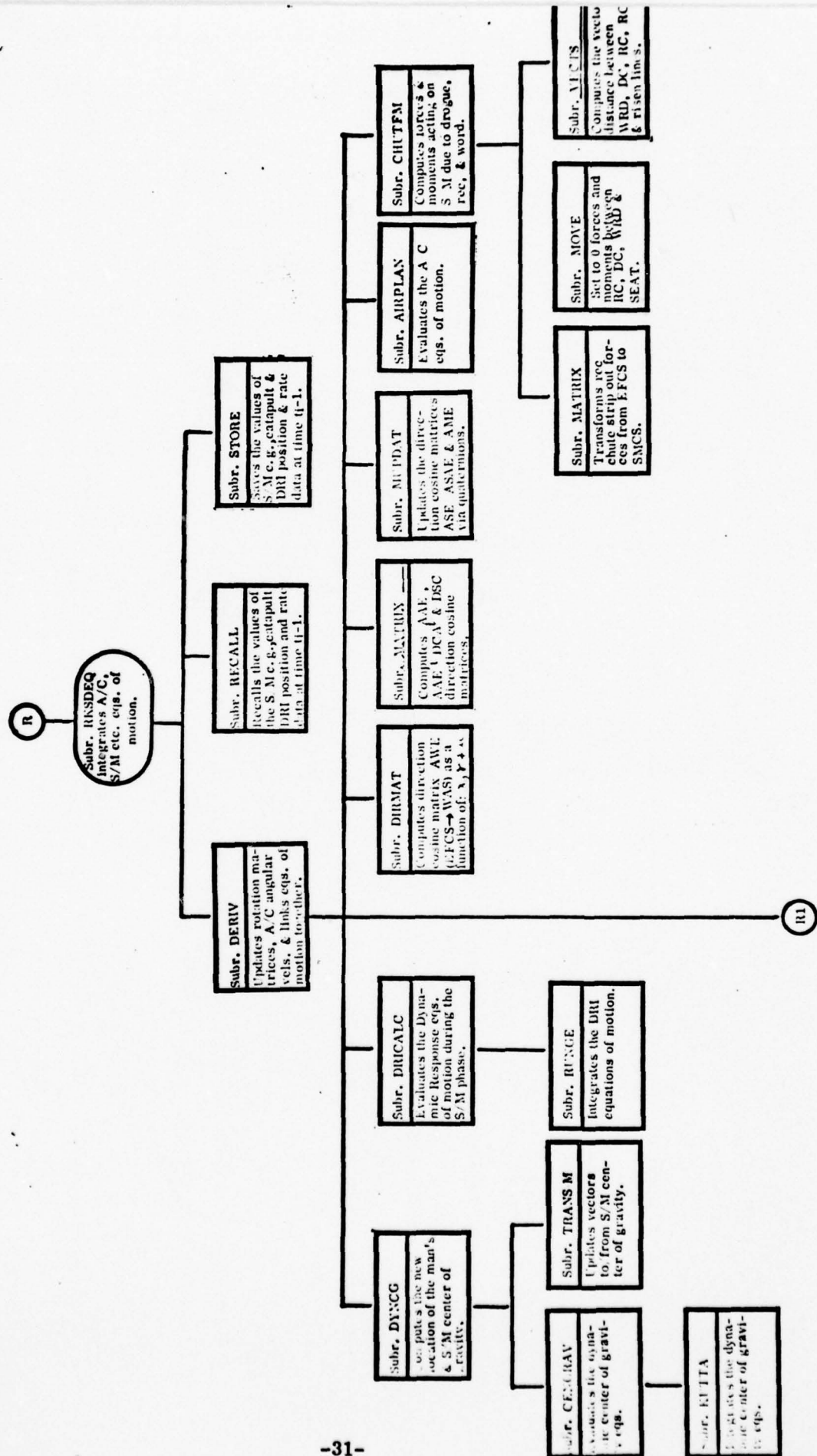
Controls overall time step ( $\Delta t$ ) to be used during each phase.

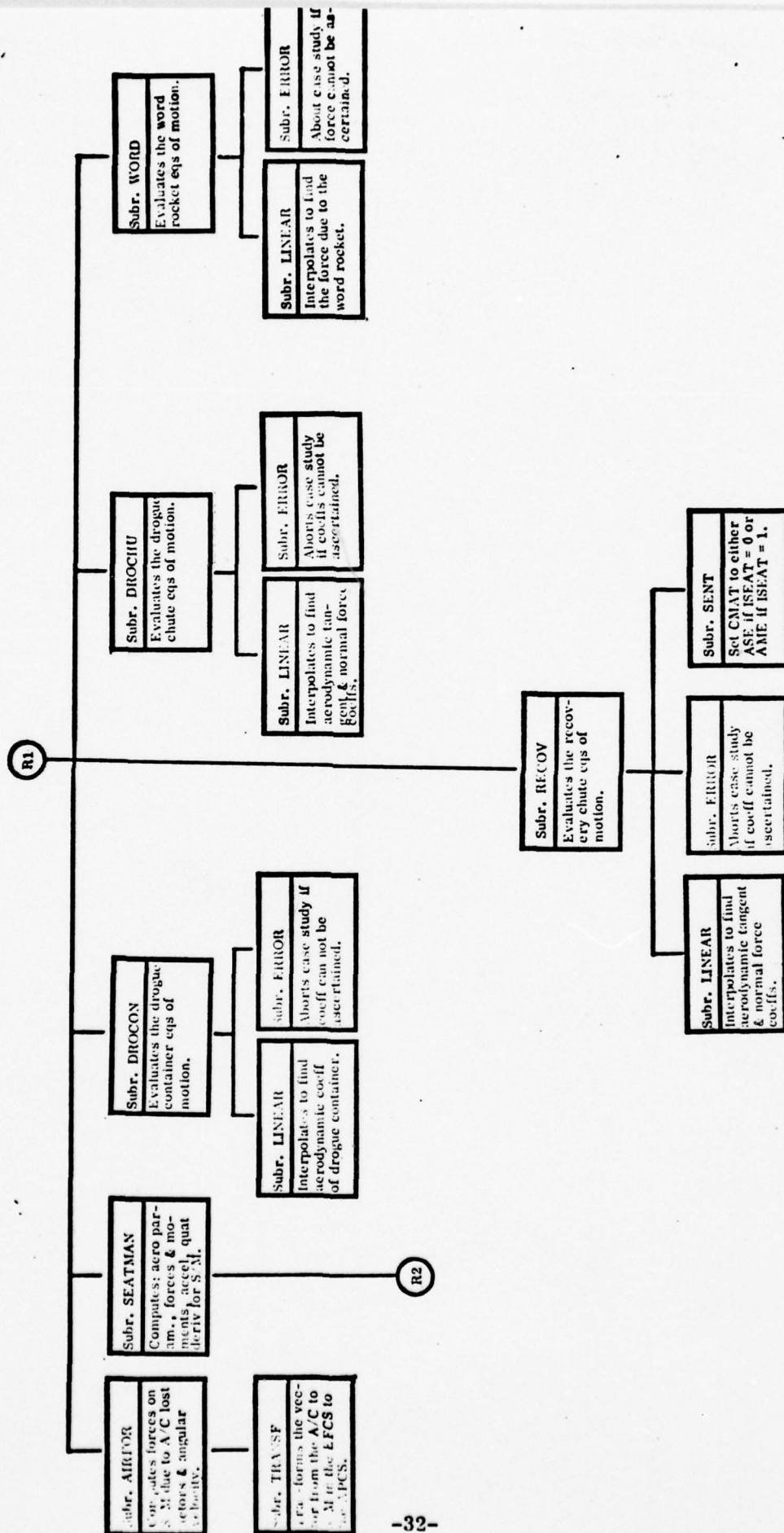
6.2      Macro Subroutine Flow Diagram



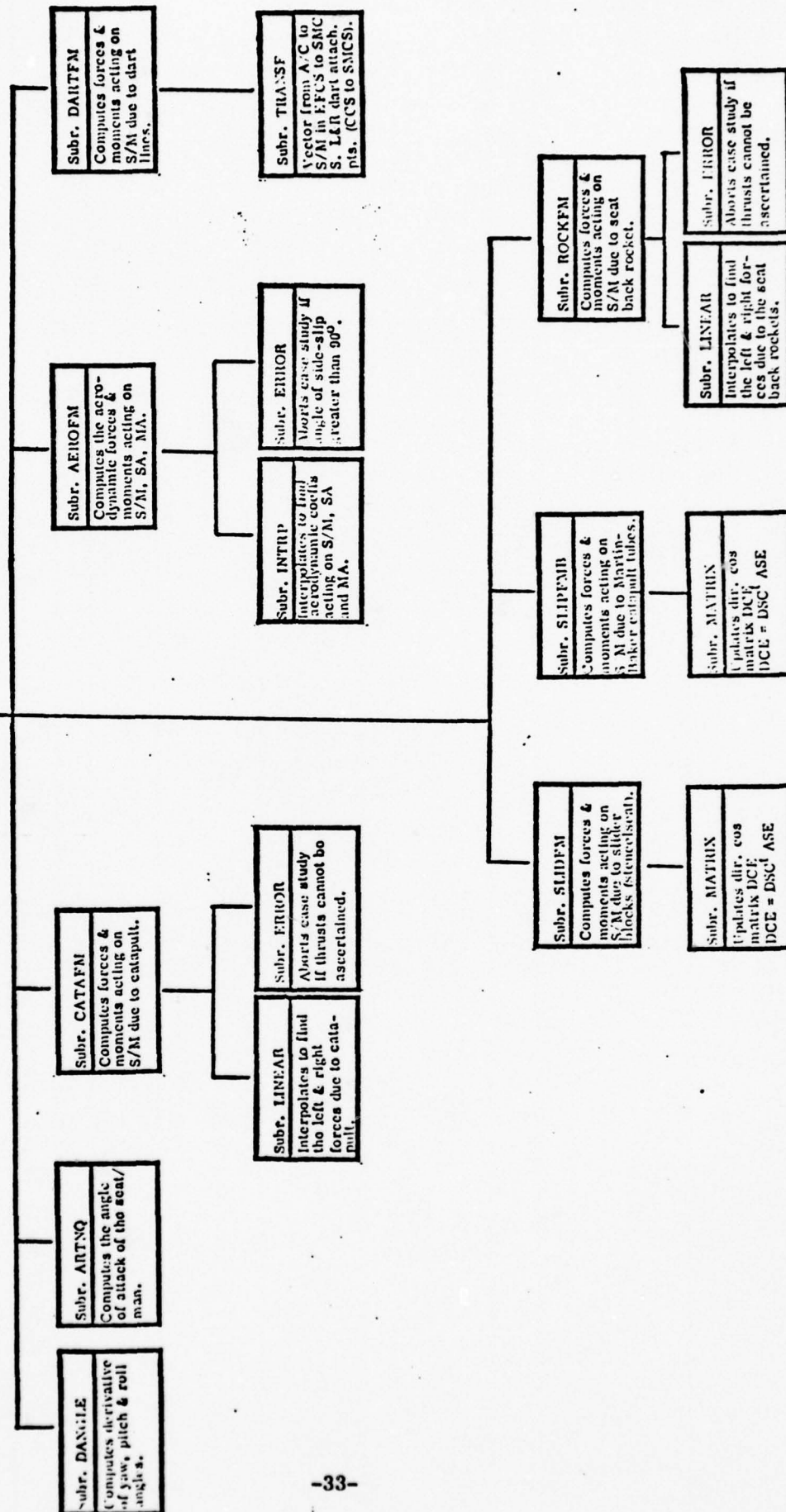






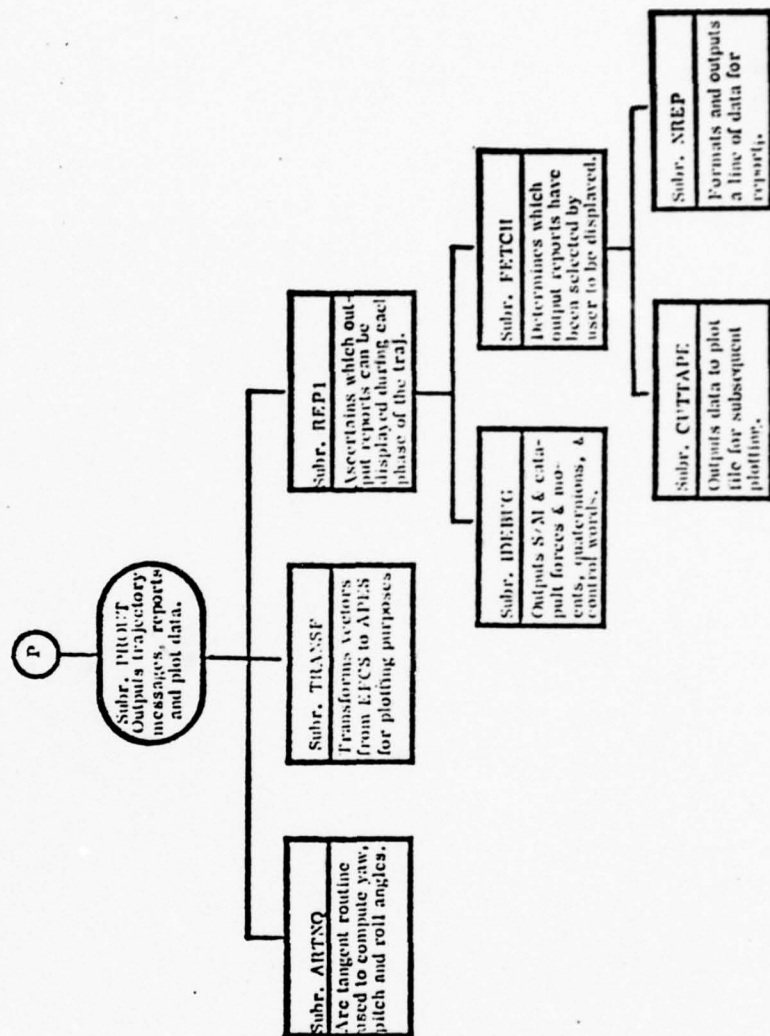
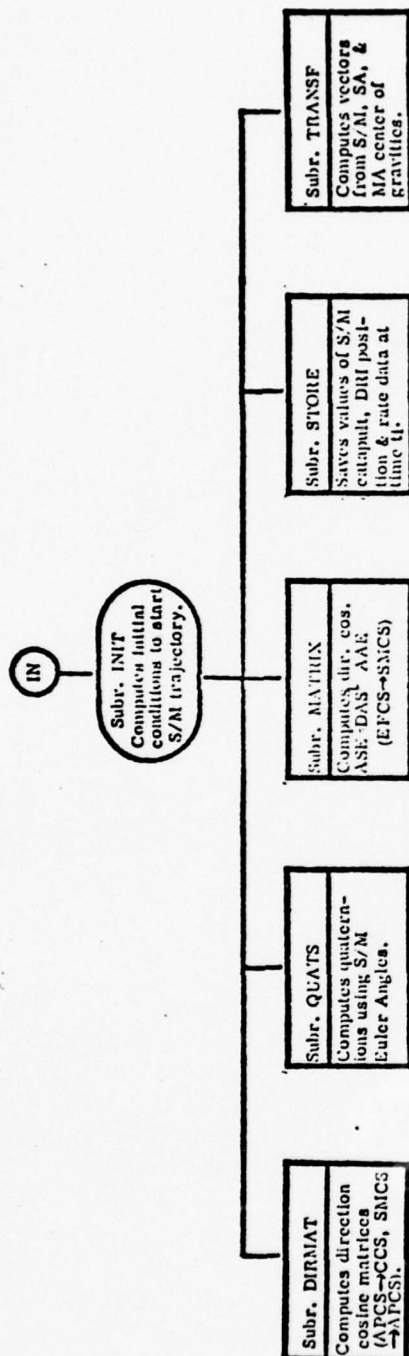


02





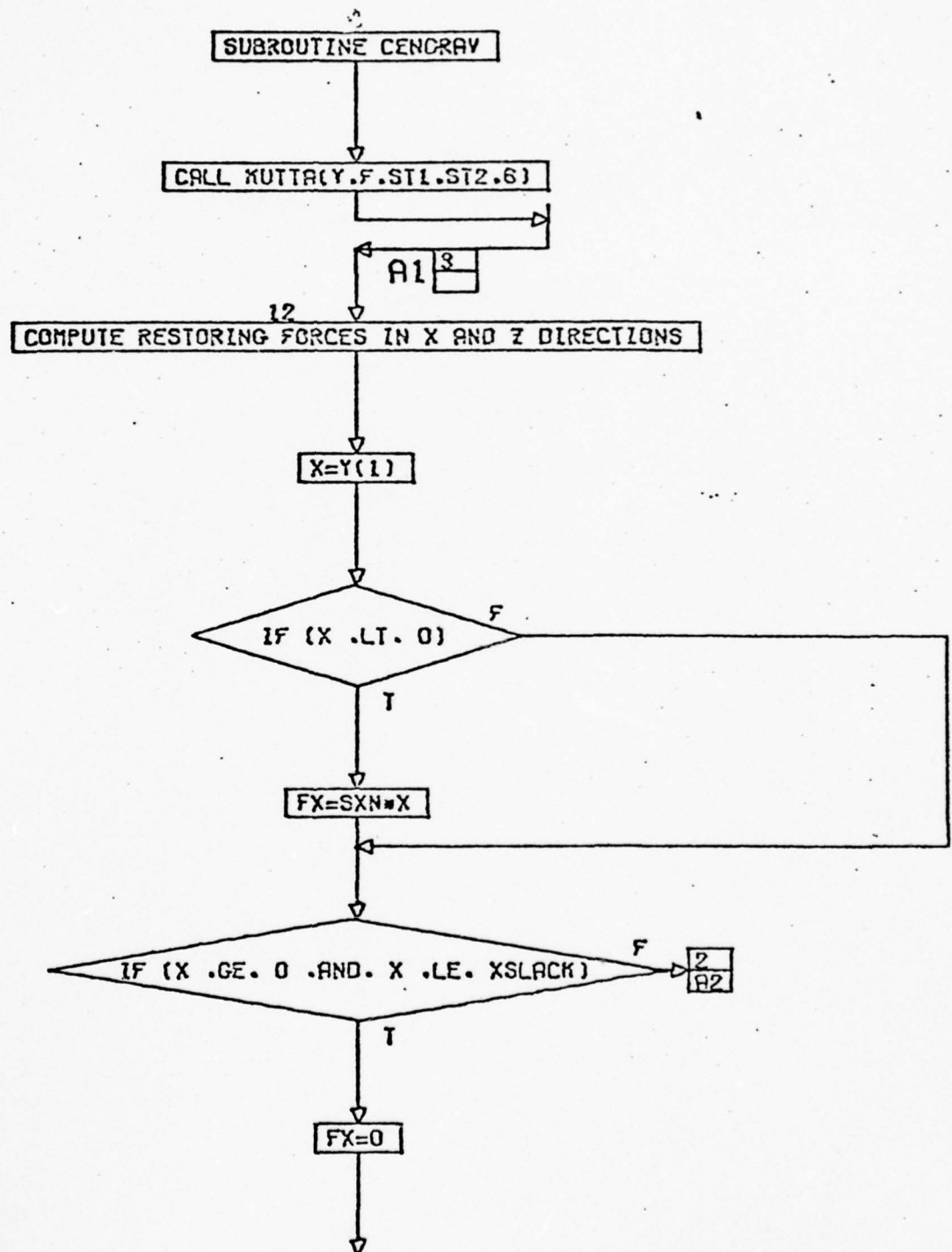




6.3

Detailed Flow Diagrams of the New Subroutines Inserted into  
ICARUS

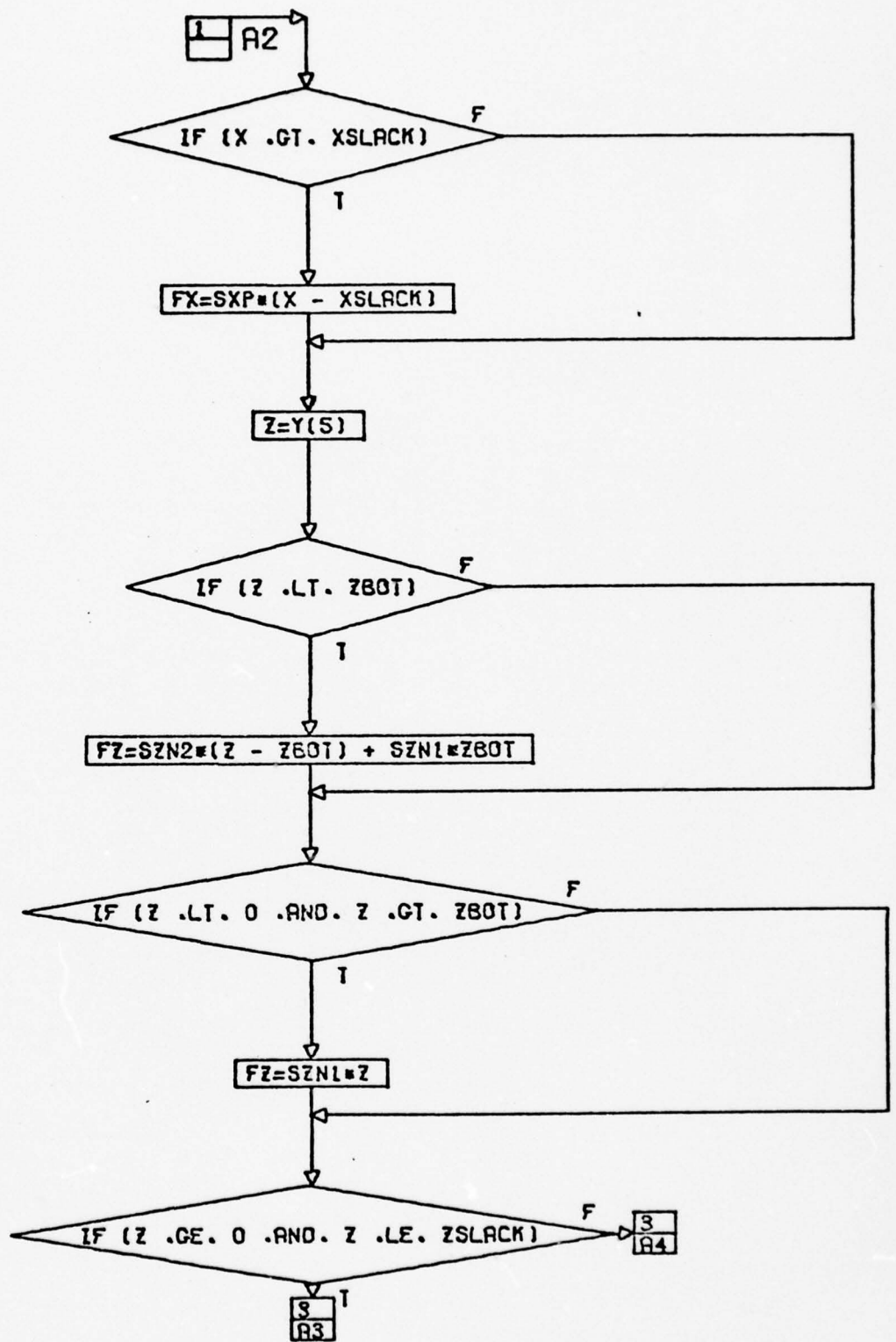
See Figure 1



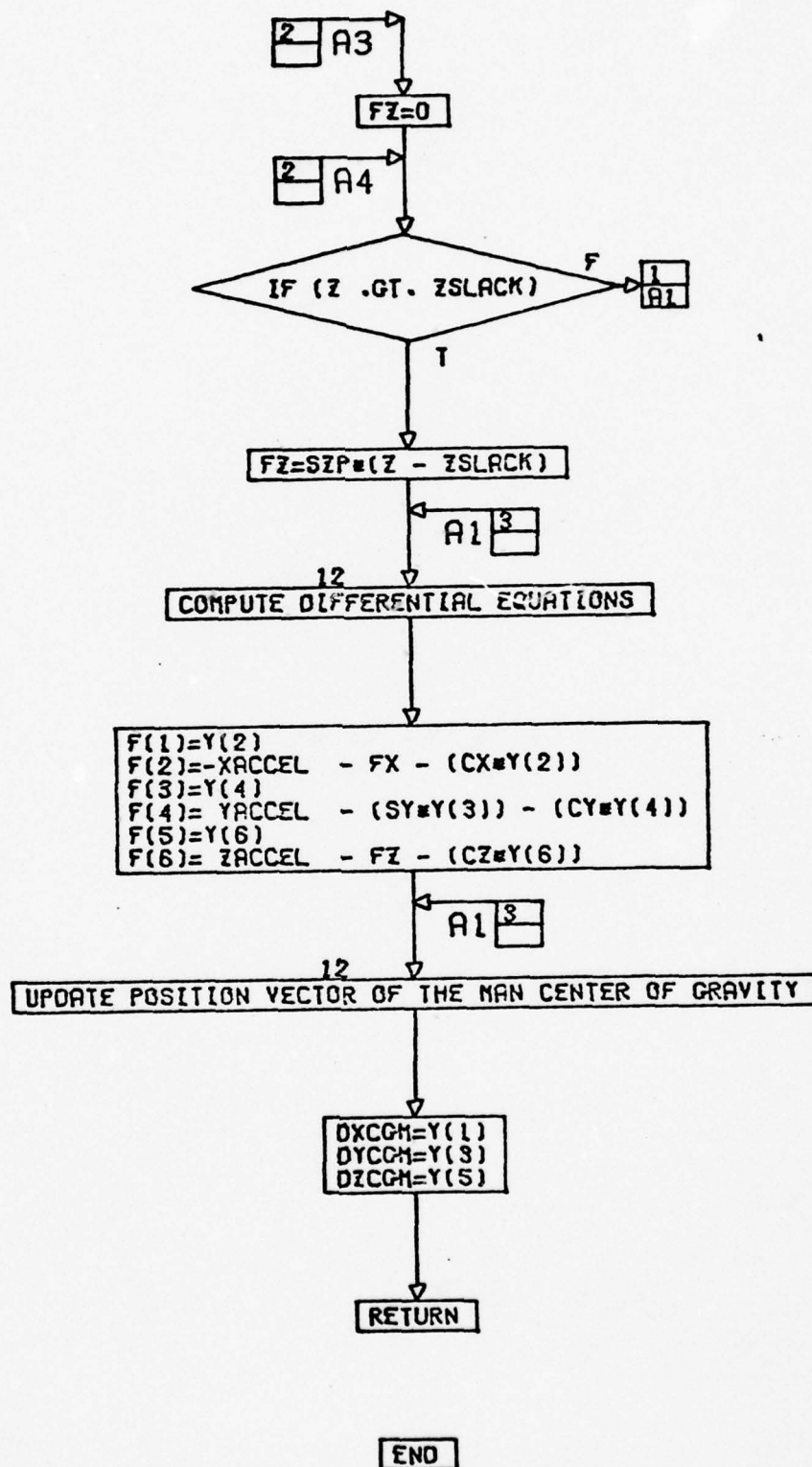
CONT. ON PG 2

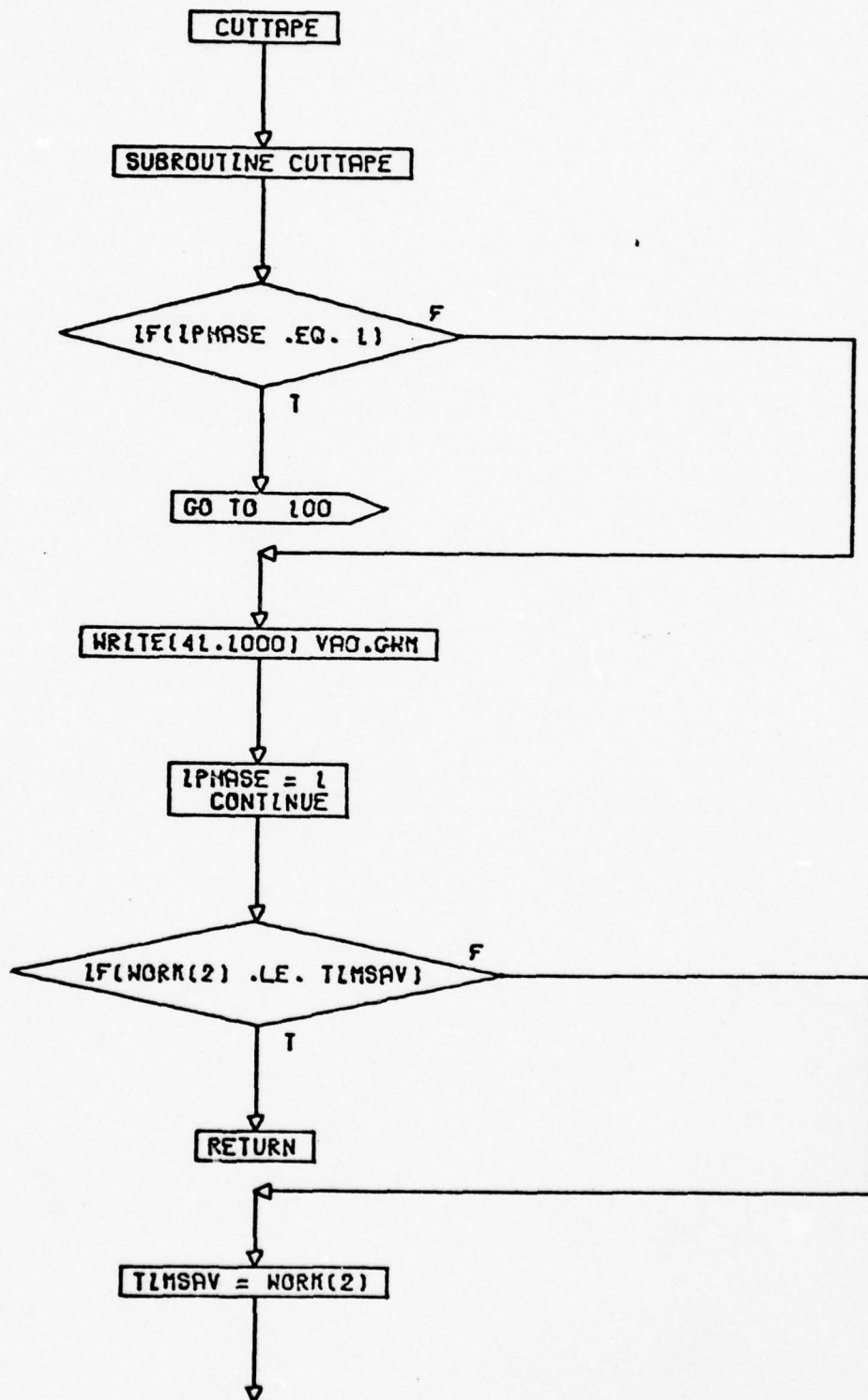
FIGURE 1

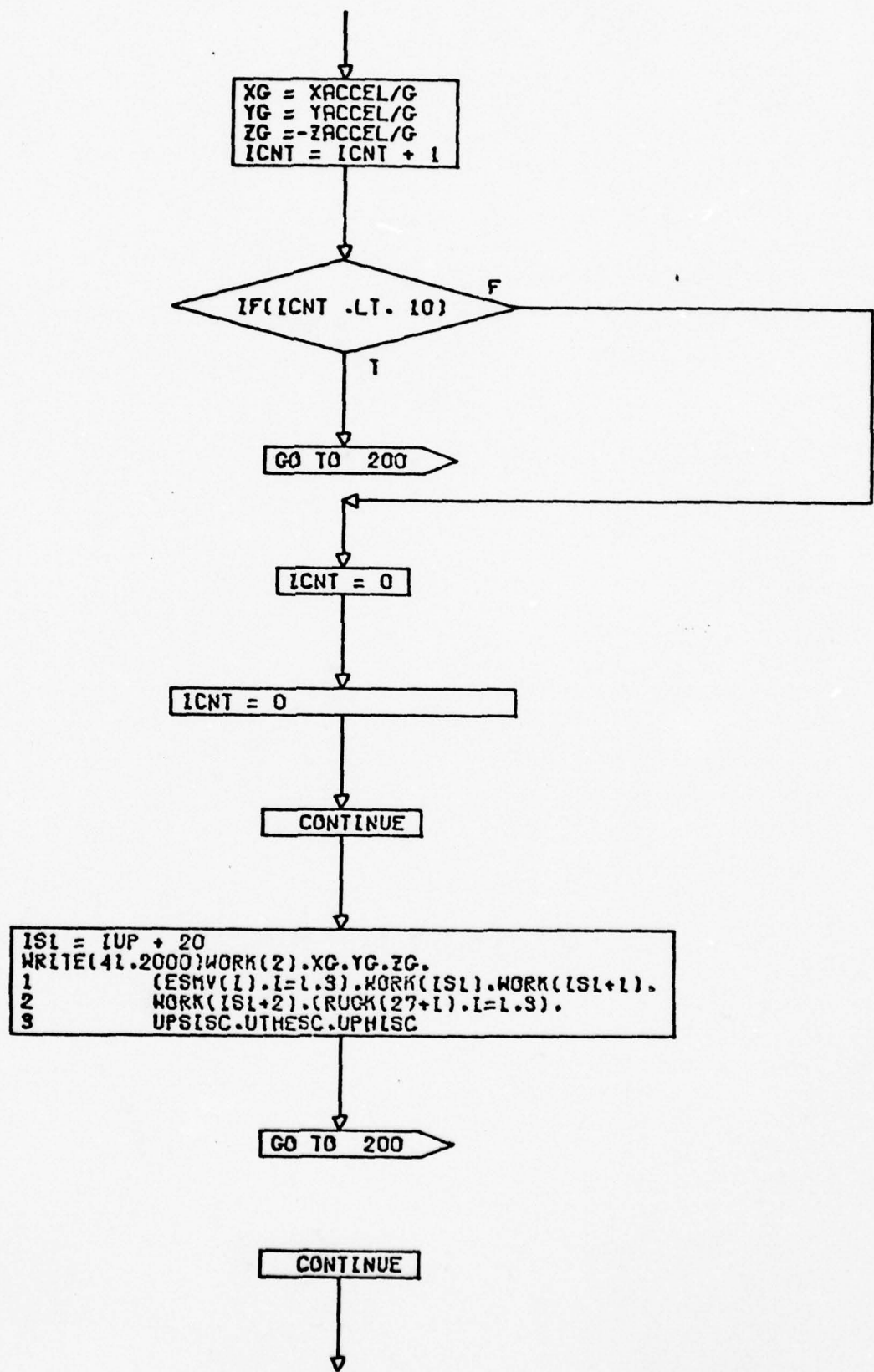




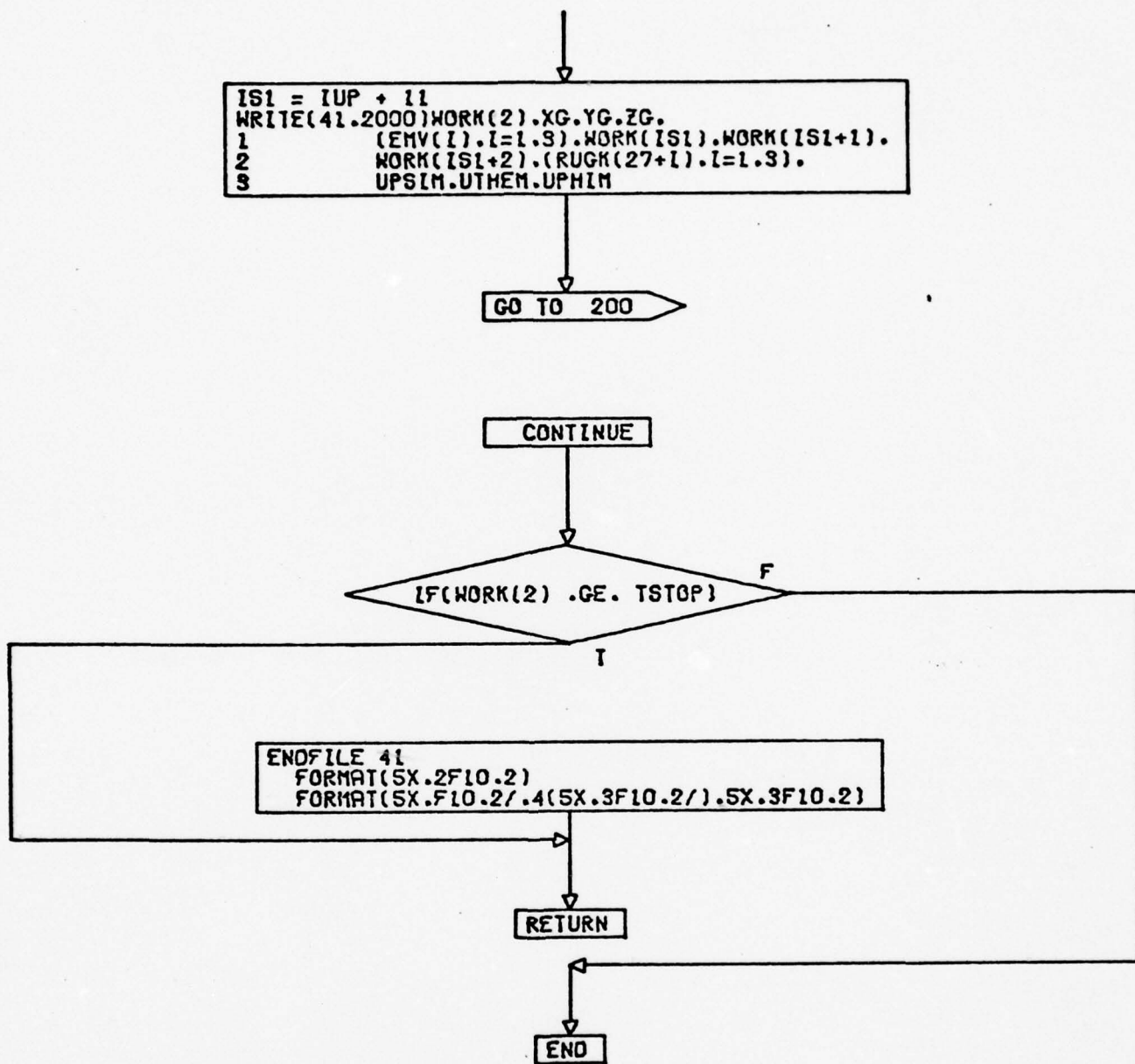
CONT. ON PG 3

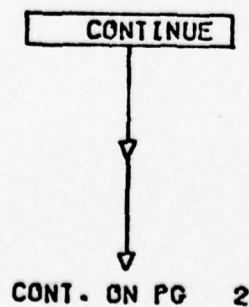
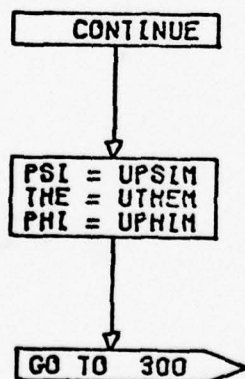
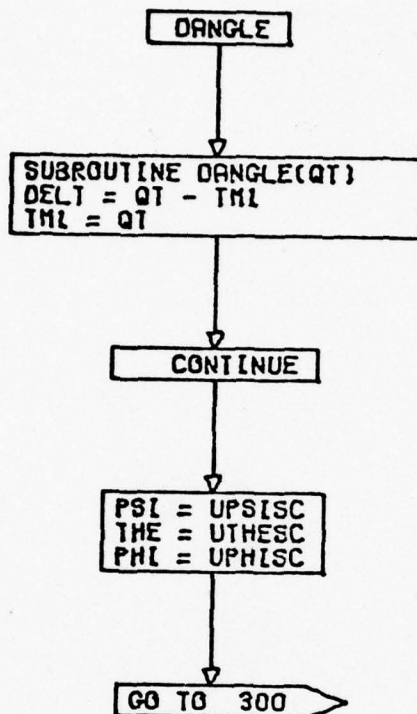


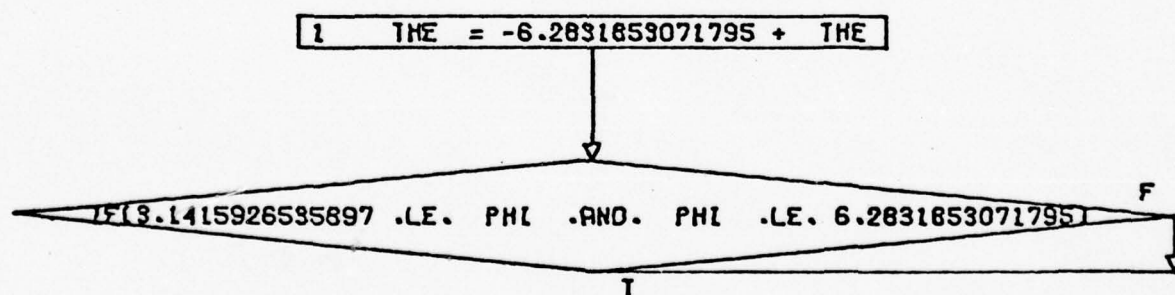
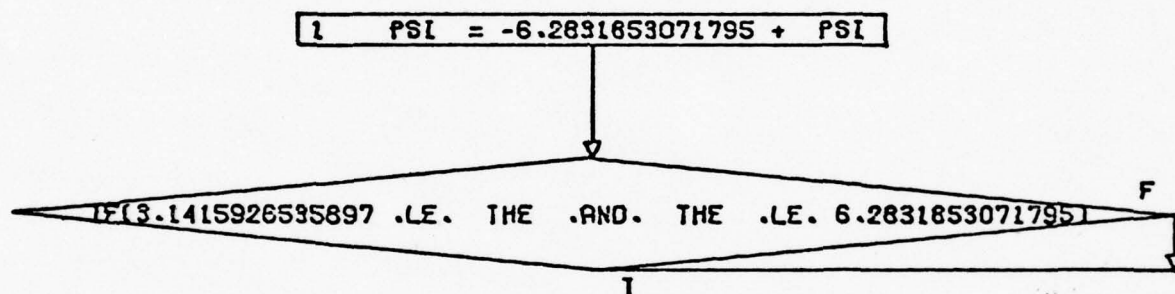
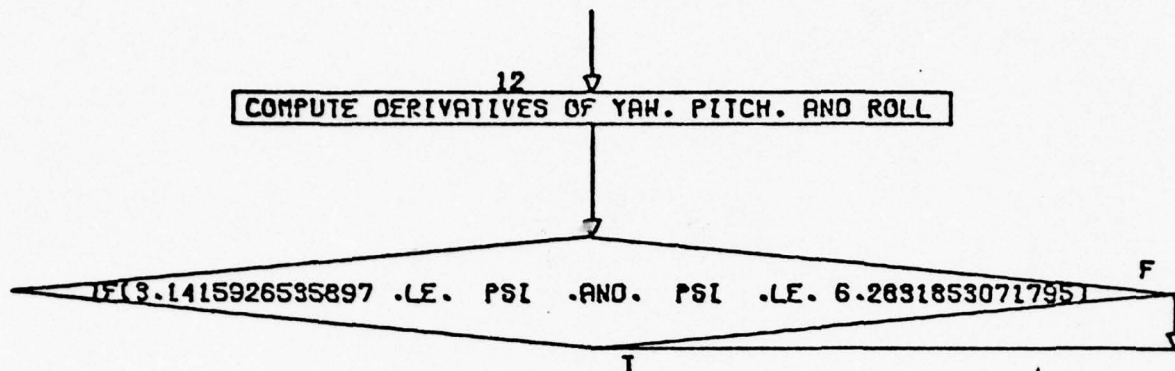






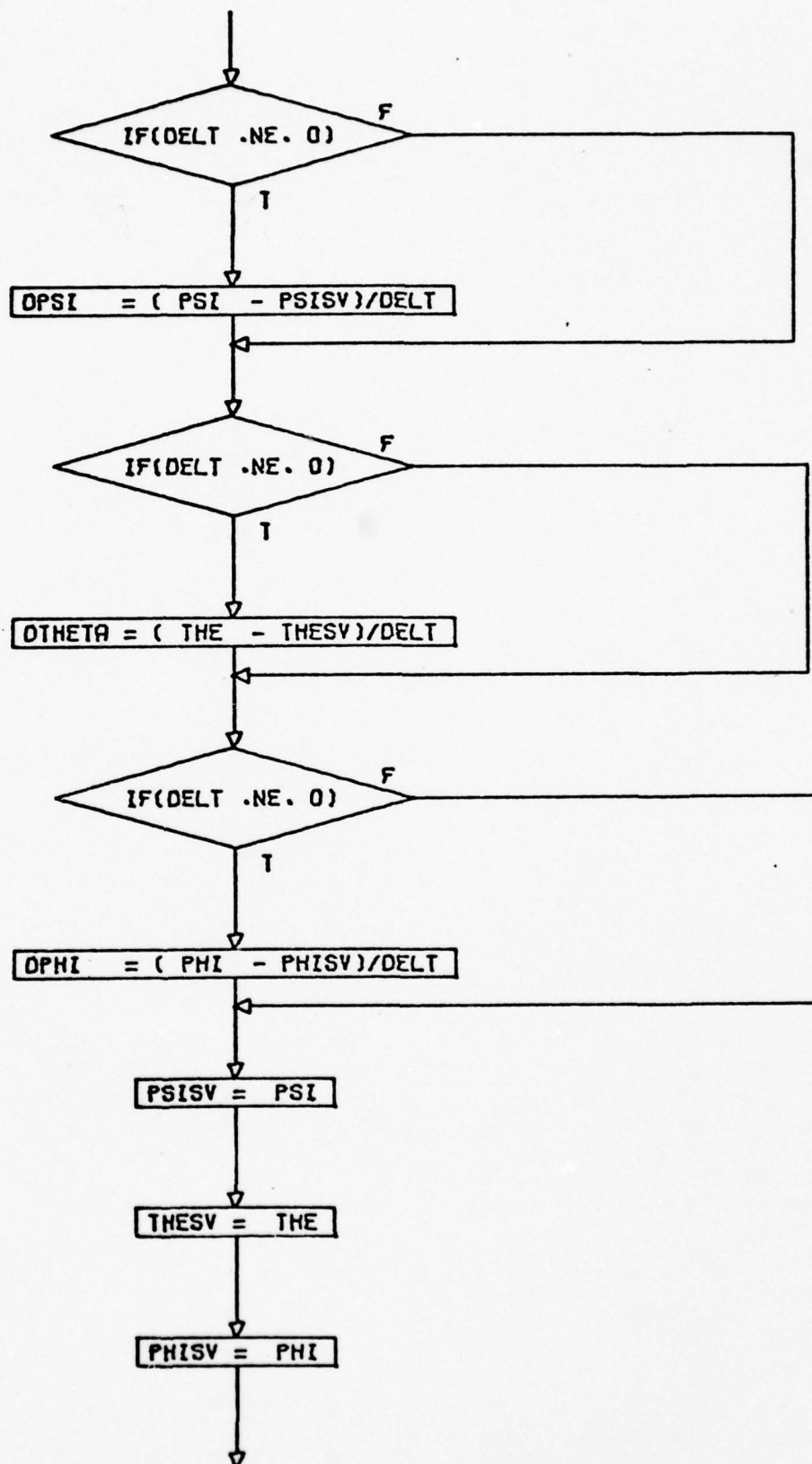






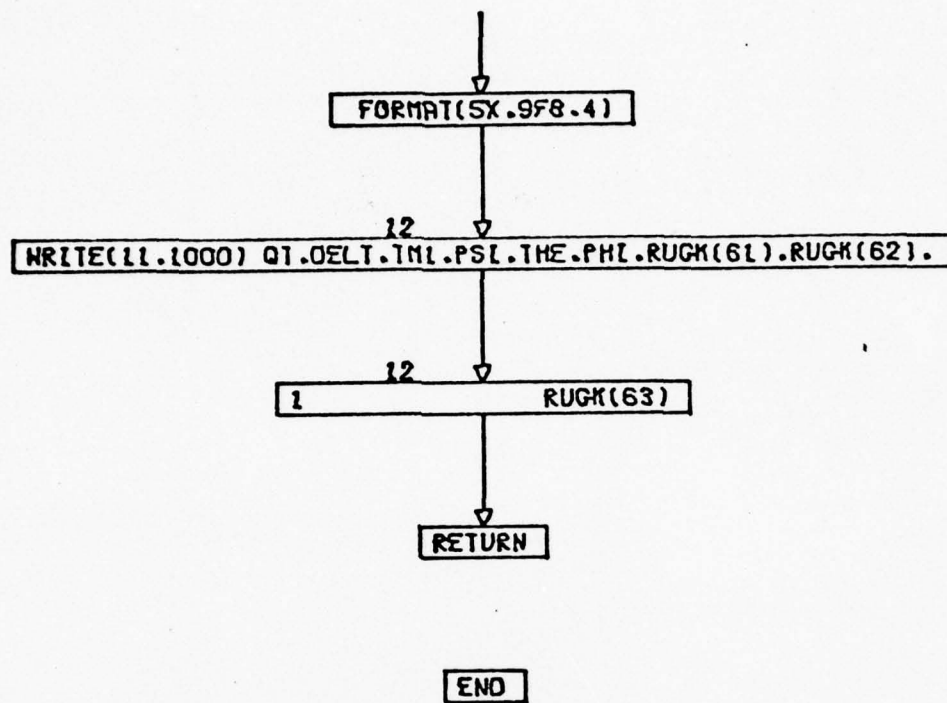
1 PHI = -6.2831853071795 + PHI

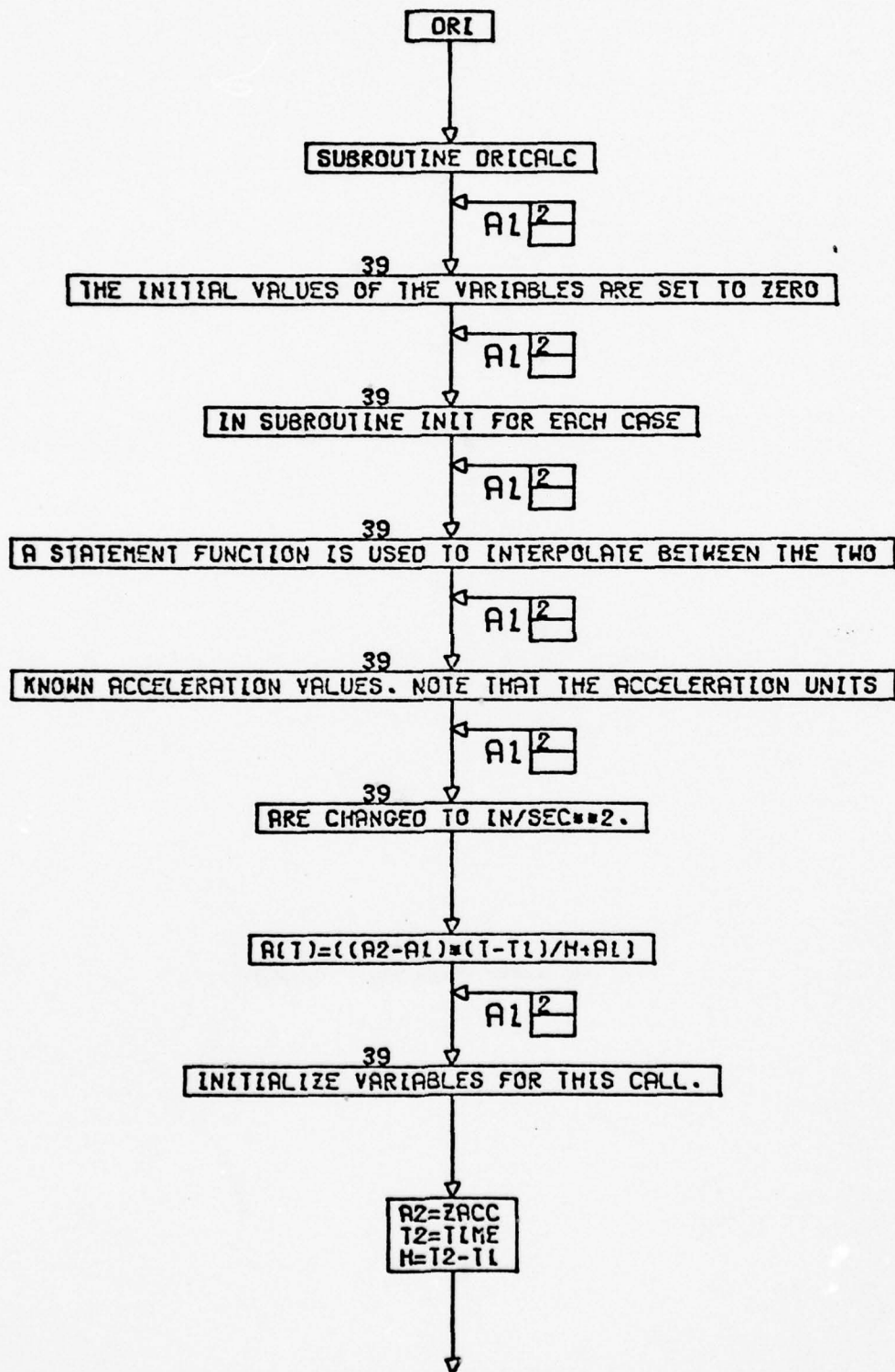
CONT. ON PG 3

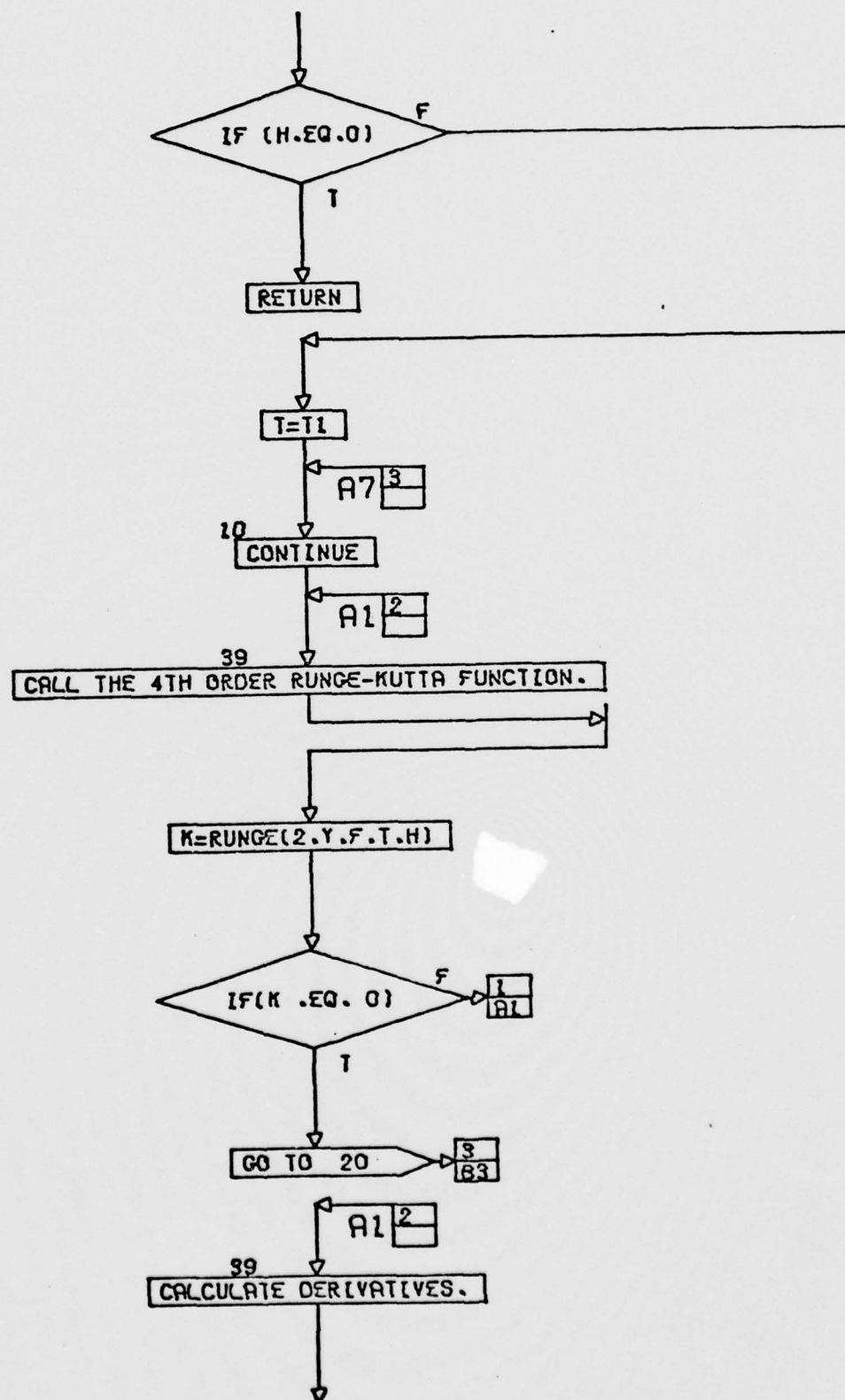


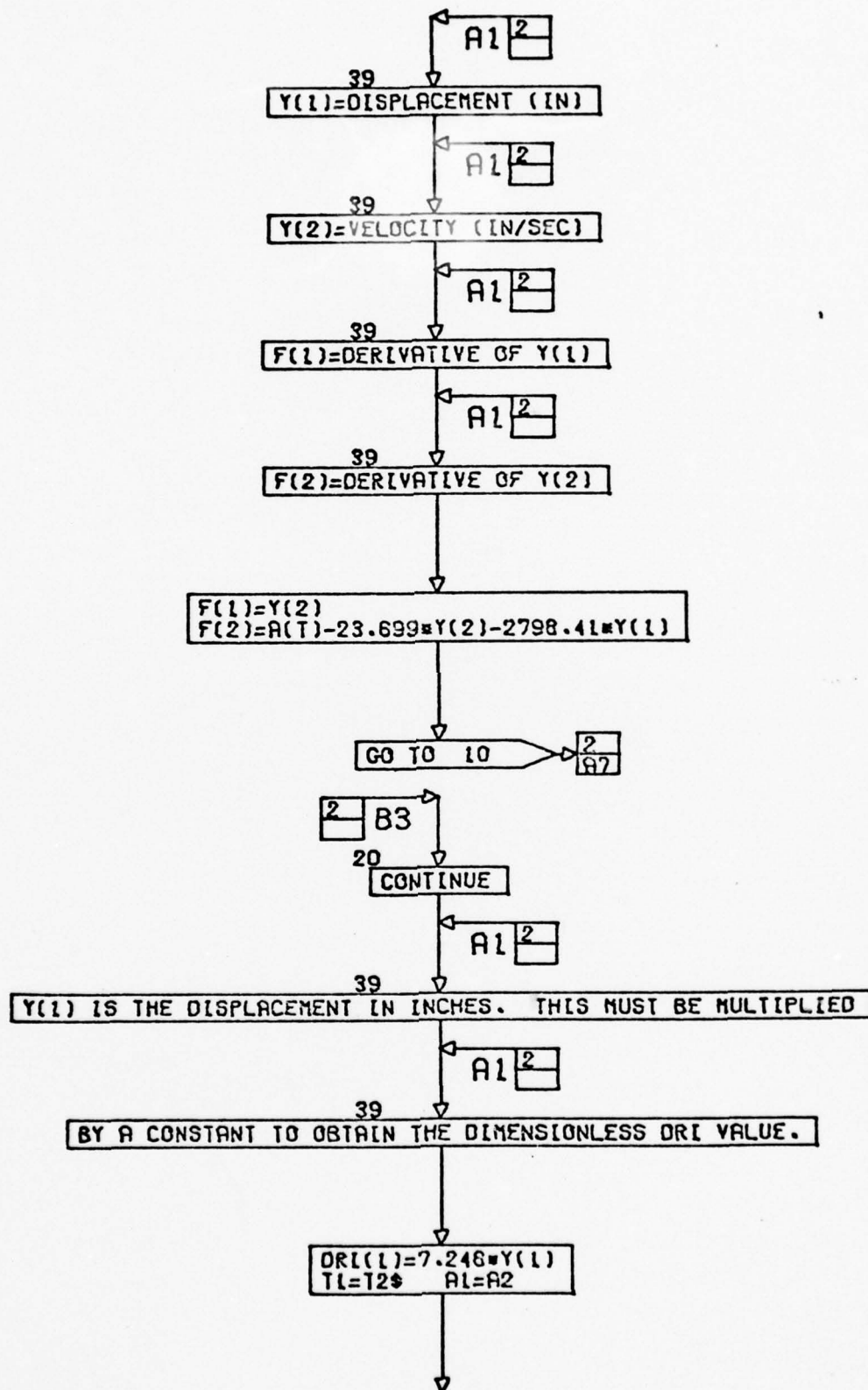
CONT. ON PG 4



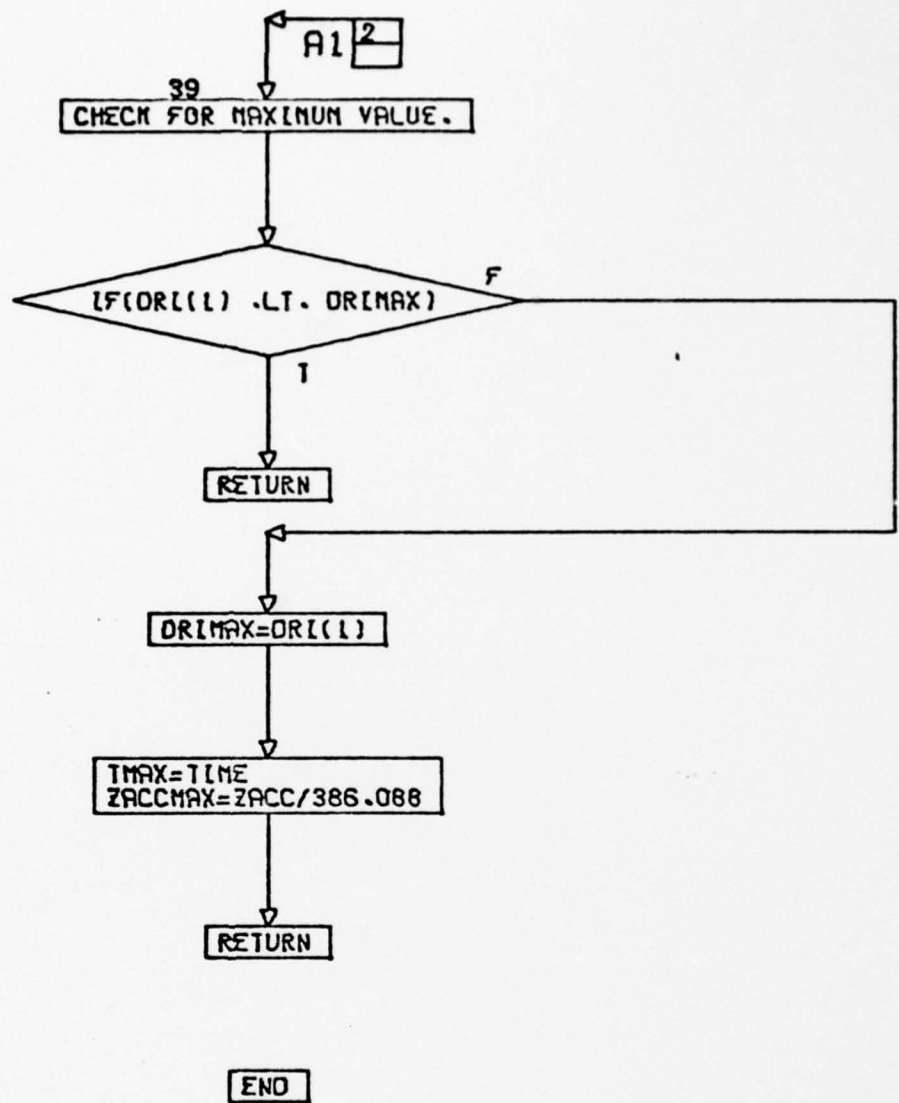


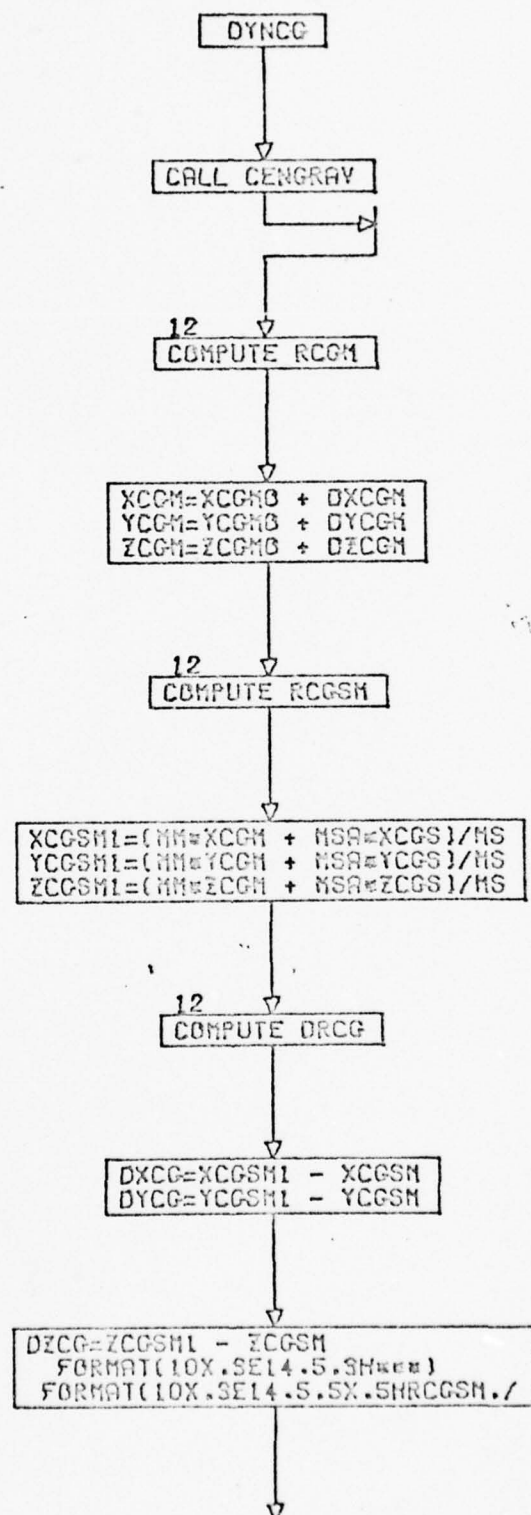












1 10X. 3E14.5.5X.5HRCCMO./  
 2 10X. 3E14.5.5X.5HRCCM ./  
 3 10X. 3E14.5.5X.5HRCCS ./  
 4 10X. 3E14.5.5X.5HORCC ./  
 5 10X. 3E14.5.5X.5HORCCM.//}

12  
 WRITE(11,2000)

12  
 1 XCGSM.YCGSM.ZCGSM.

12  
 2 XCGMO.YCGMO.ZCGMO.

12  
 3 XCGM .YCGM .ZCGM .

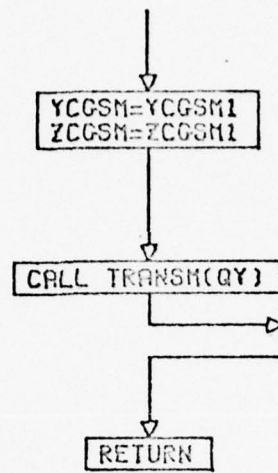
12  
 . XCGS.YCGS.ZCGS.

12  
 4 DXCG .DYCG .DZCG .

12  
 5 DXCGM.DYCGM.DZCGM

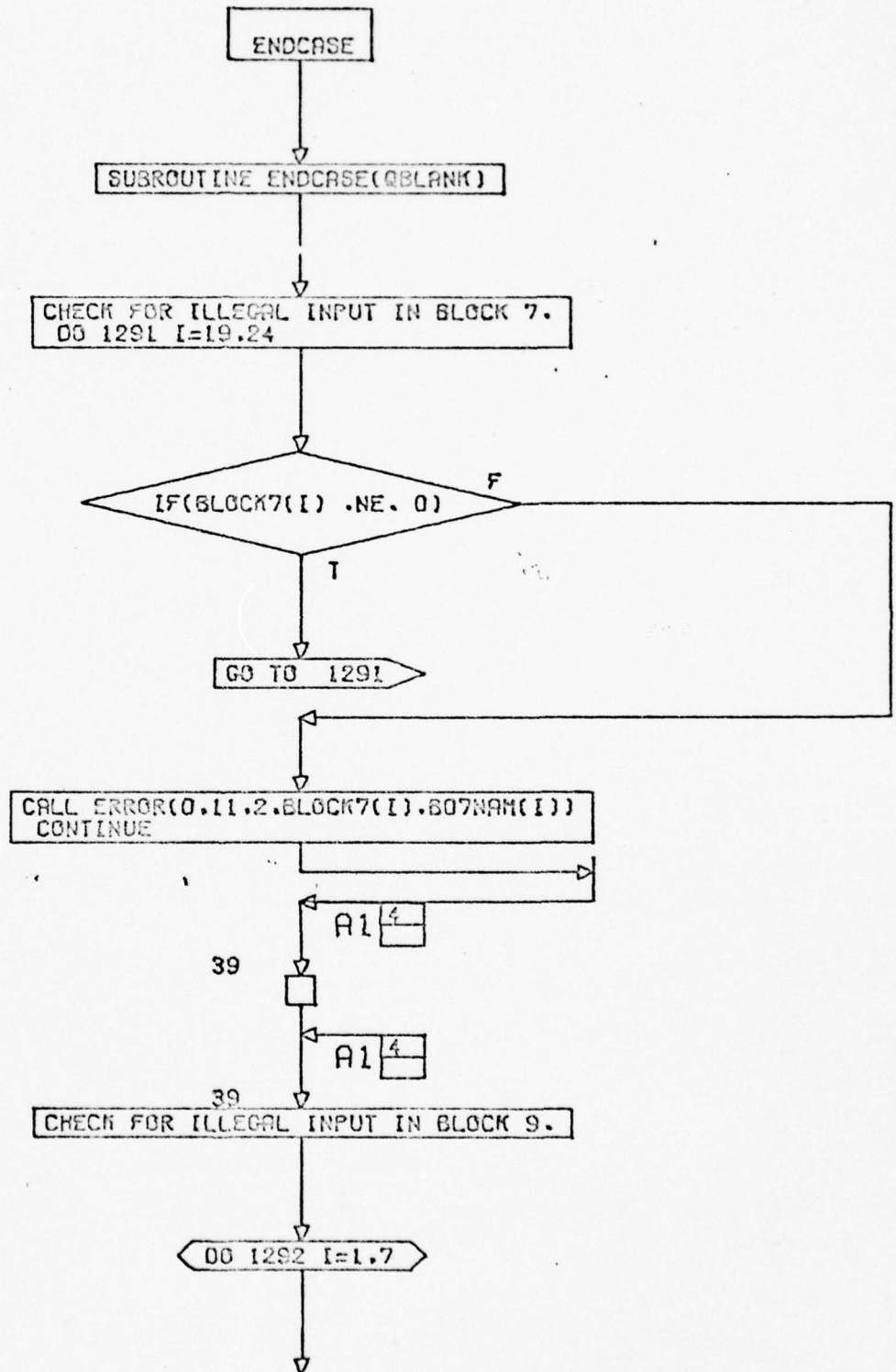
12  
 UPDATE RCGSM

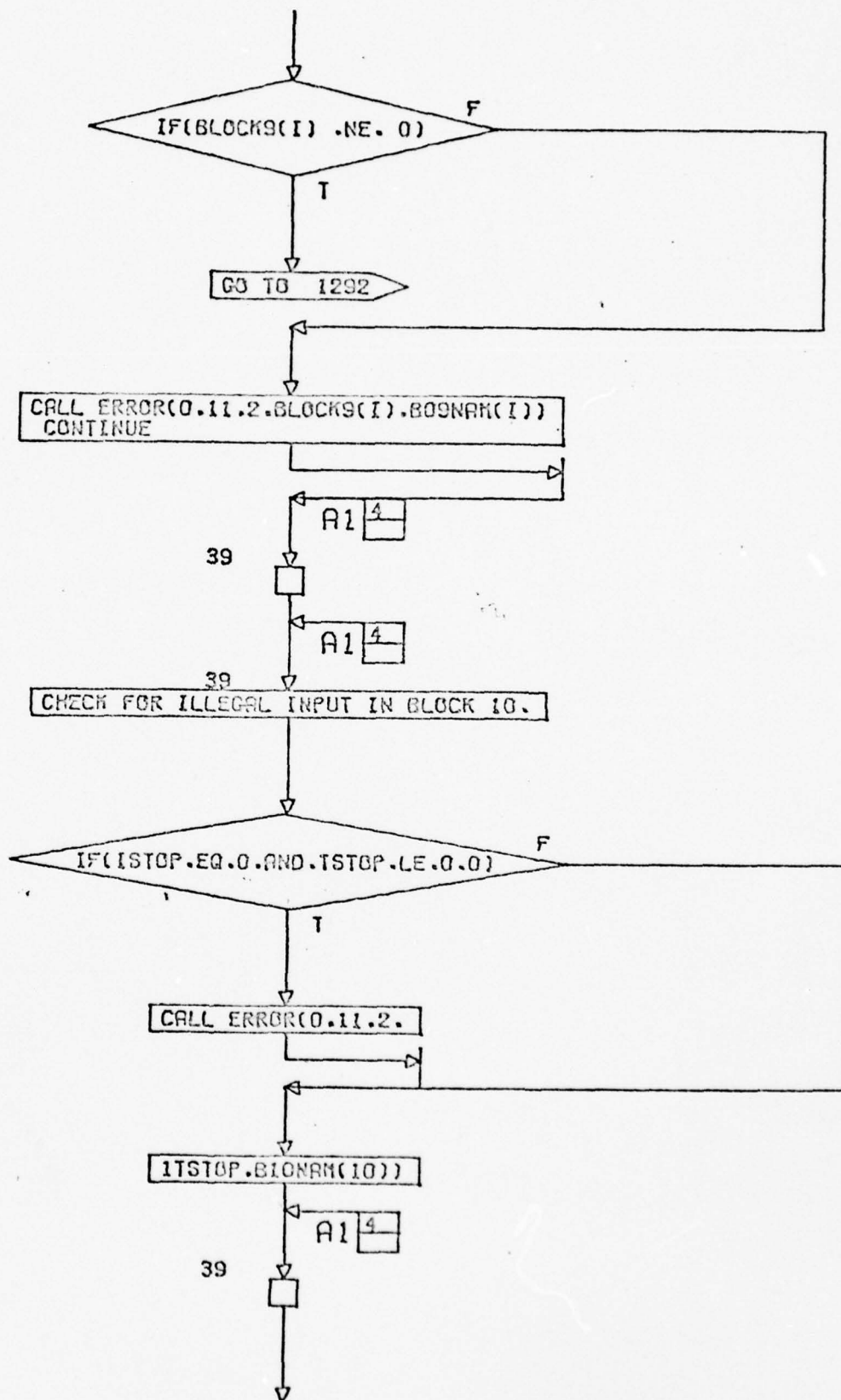
XCGSM=XCGSM1



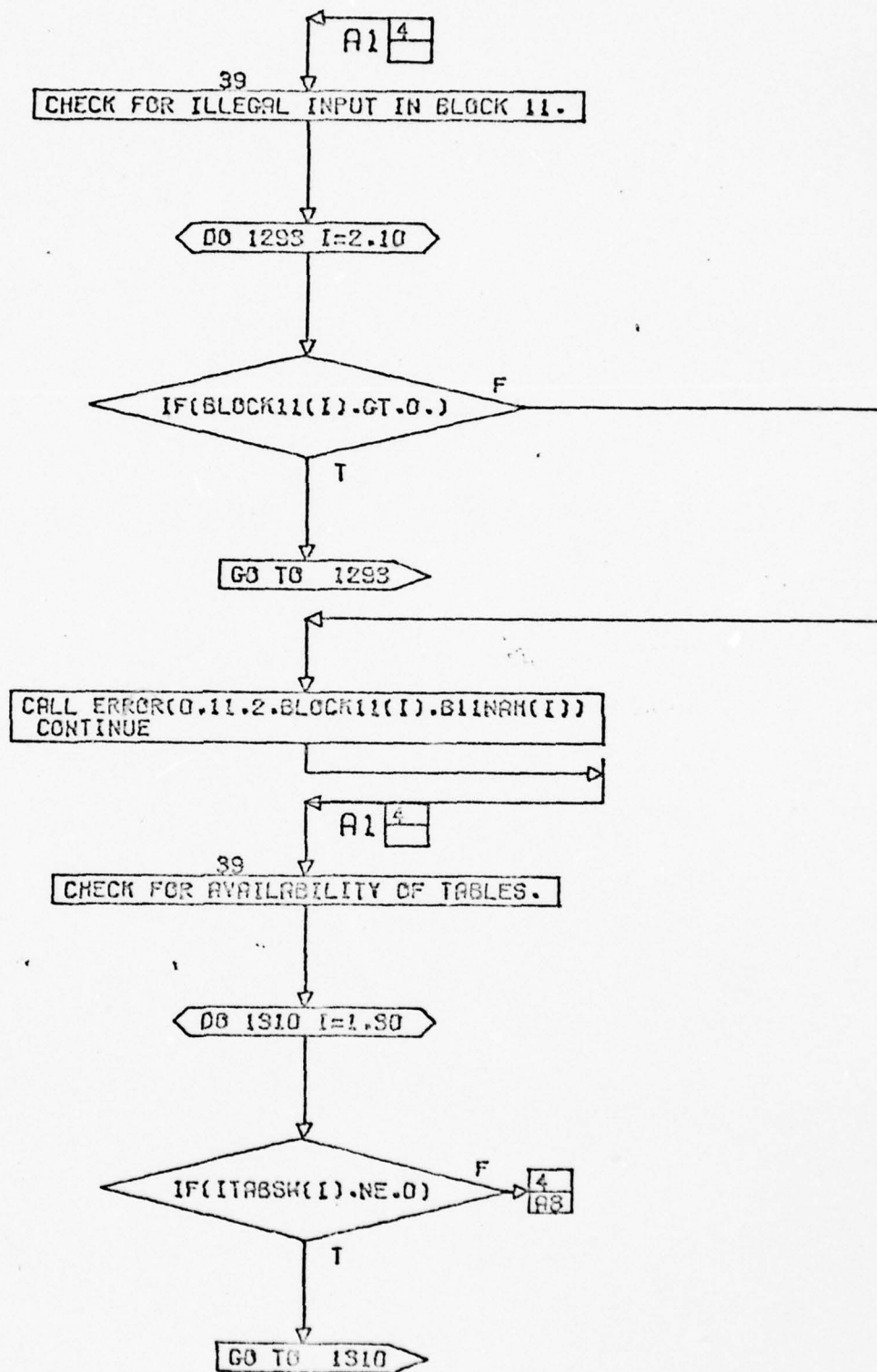
END

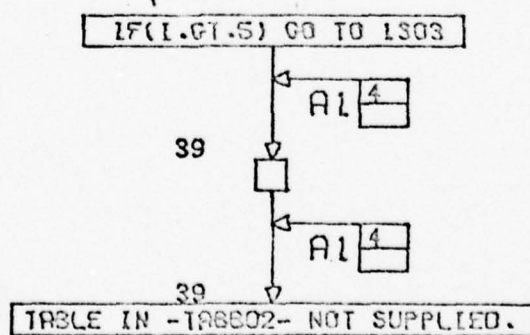
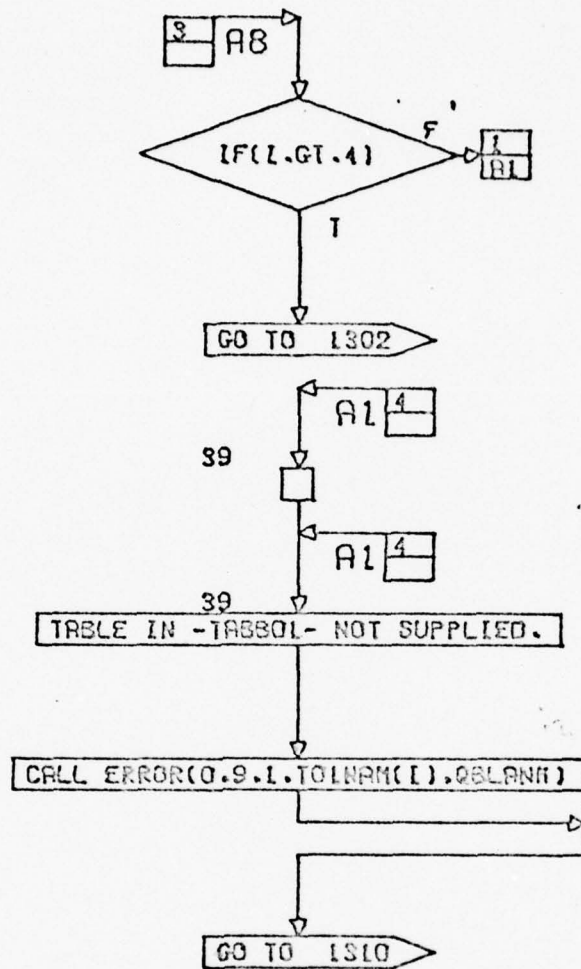






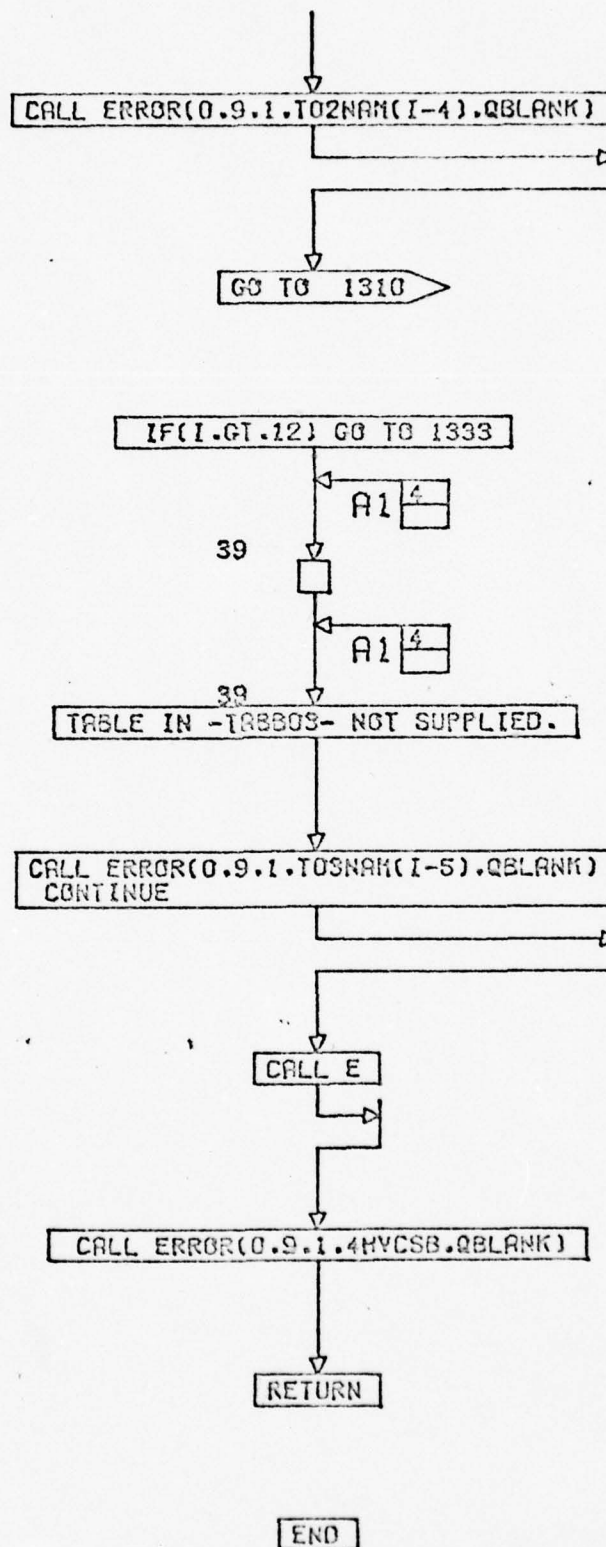
CONT. ON PG 3

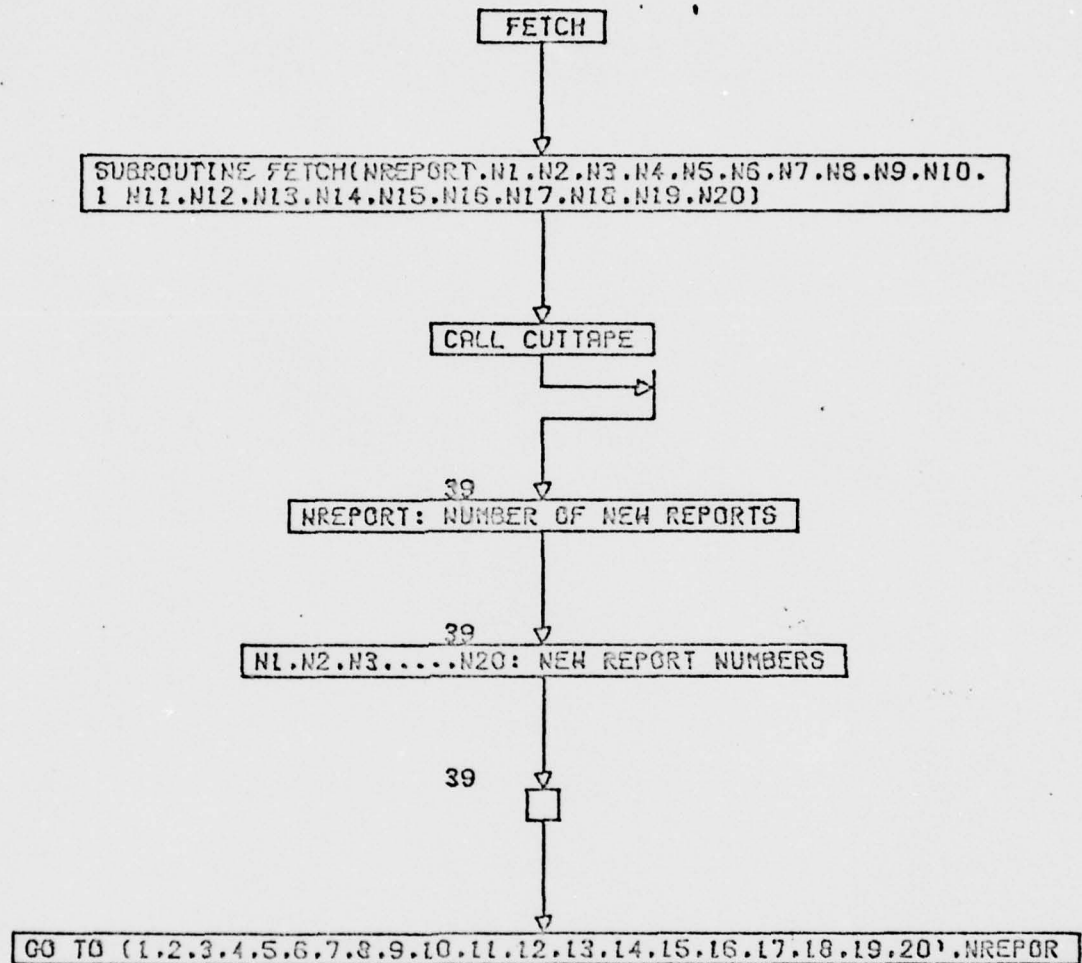




CONT. ON PG 5







N(20)=N20  
 N(19)=N19  
 N(18)=N18  
 N(17)=N17  
 N(16)=N16  
 N(15)=N15  
 N(14)=N14

N(13)=N13  
N(12)=N12  
N(11)=N11  
N(10)=N10  
N(9)=N9  
N(8)=N8  
N(7)=N7  
N(6)=N6

N(5)=N5  
N(4)=N4  
N(3)=N3  
N(2)=N2  
N(1)=N1

39

DO 300 I='NREPORT

J=N(I)

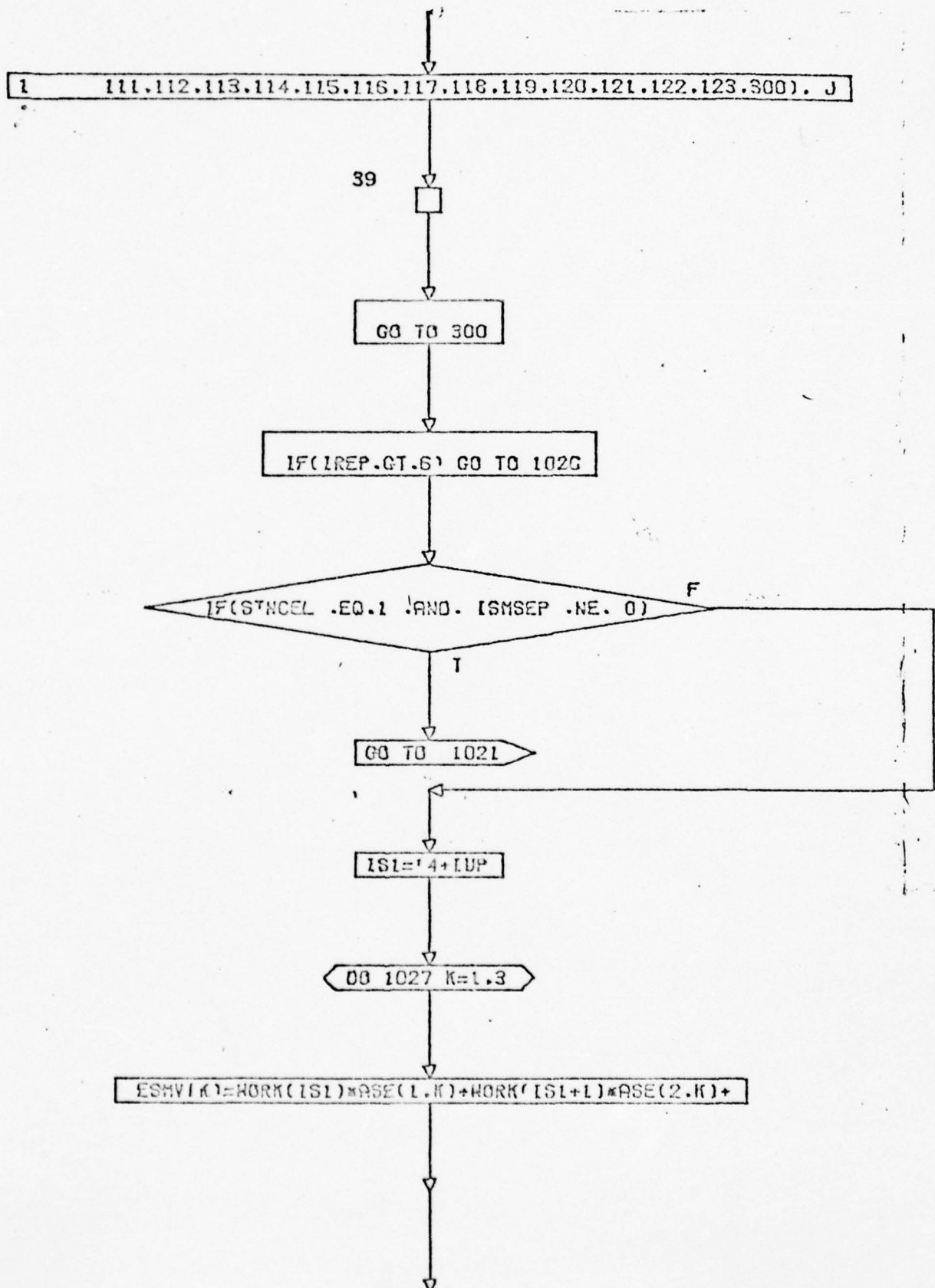
IF(IRS(J).EQ.0)

F

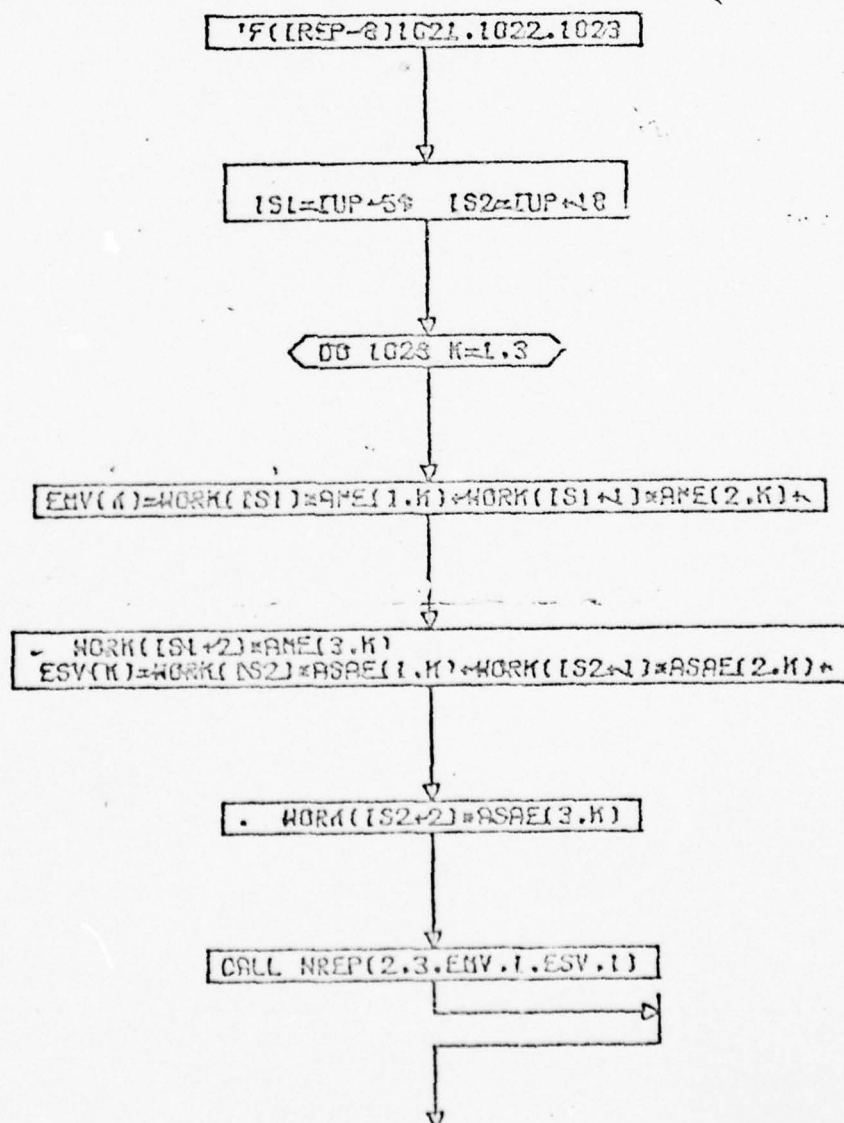
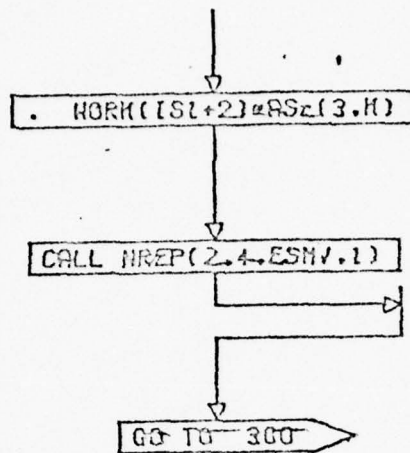
T

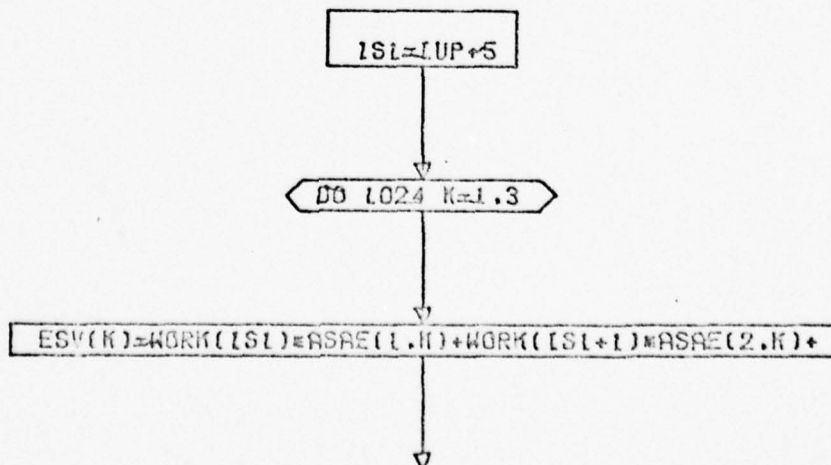
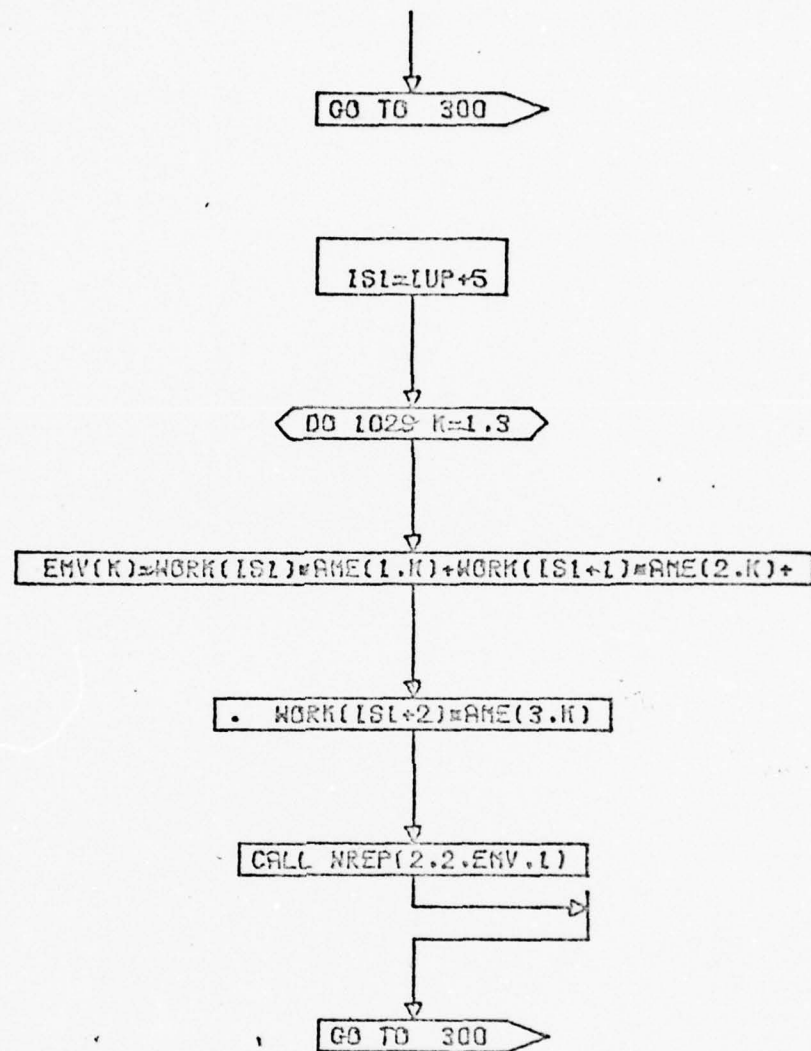
GO TO 300

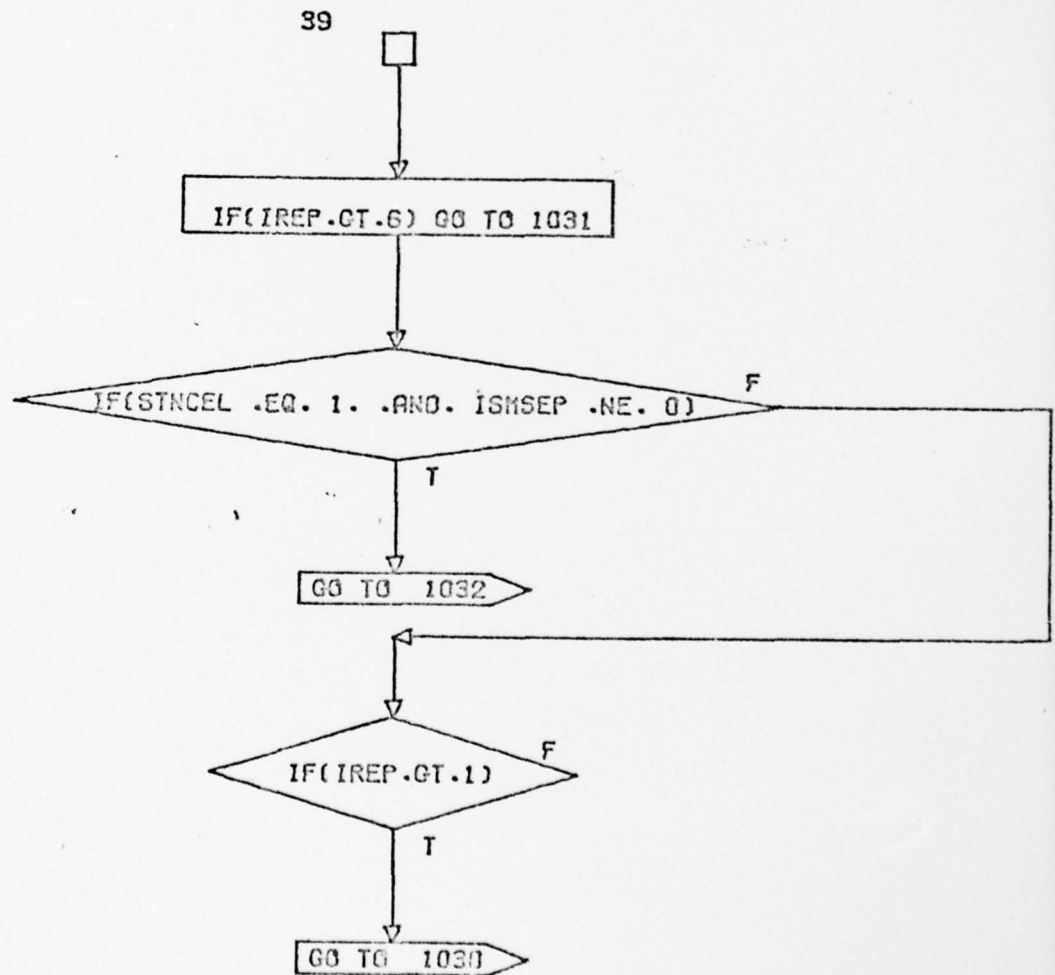
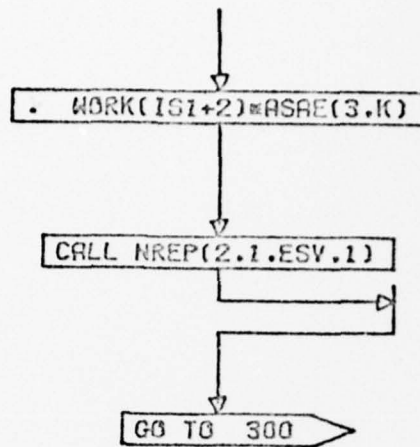
GO TO 101,102,103,104,105,106,107,108,109,110.

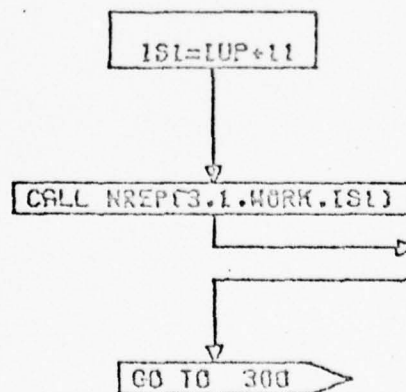
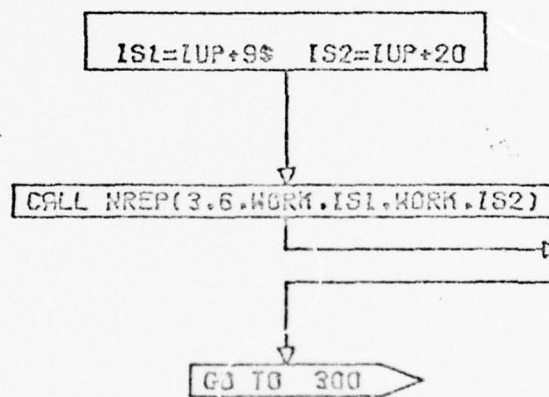
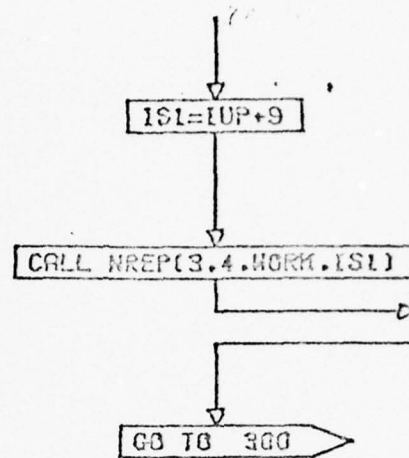




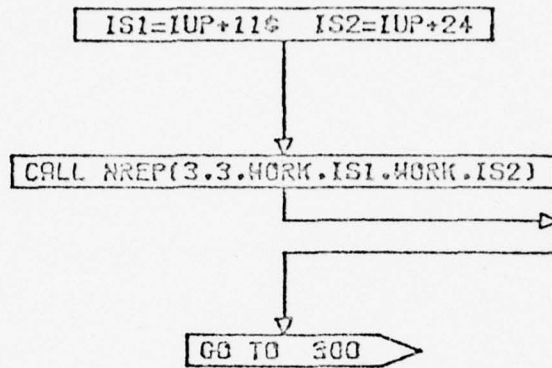




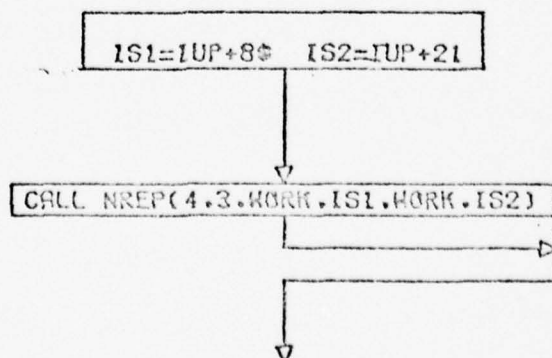
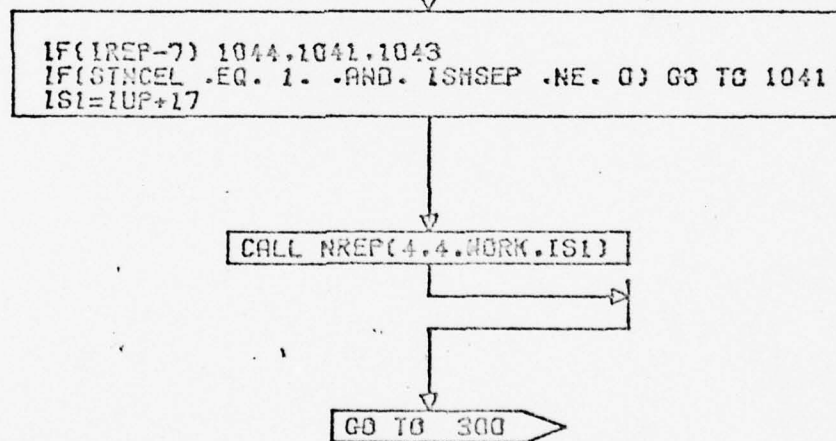


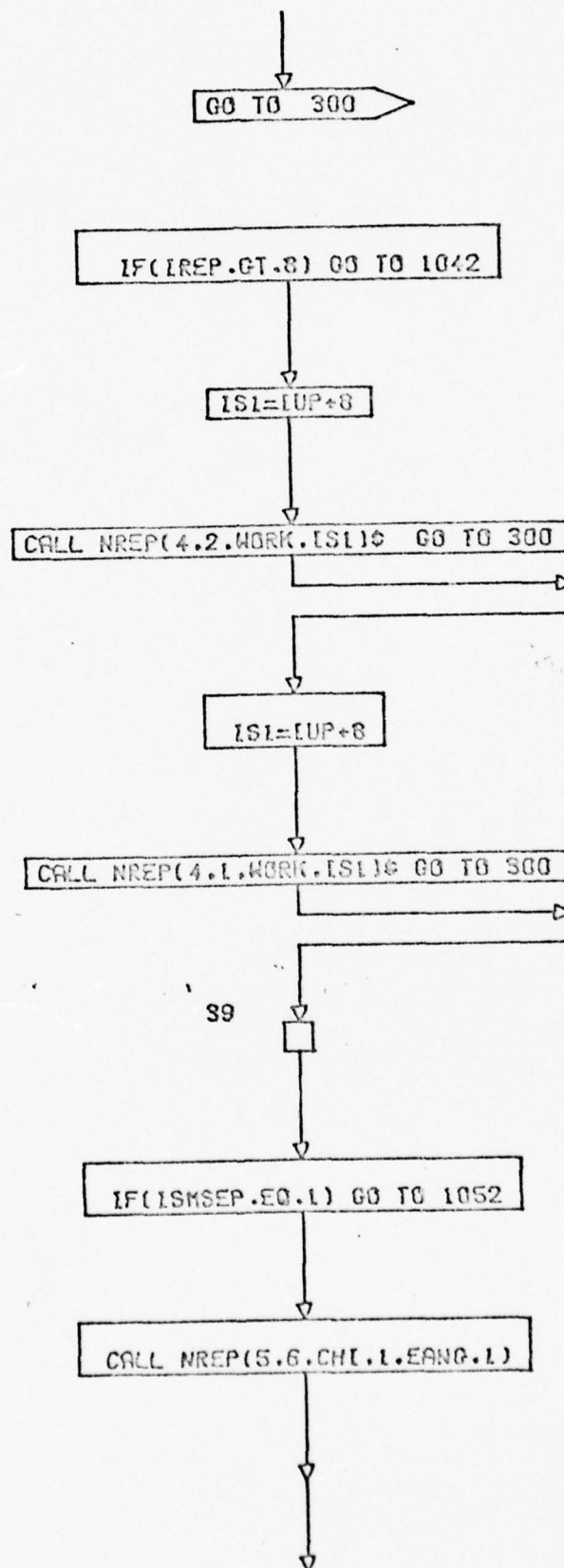


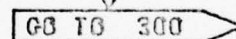
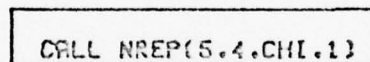
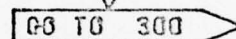
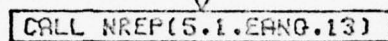
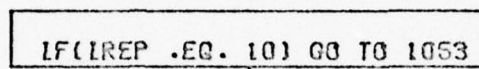
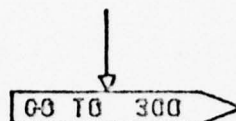




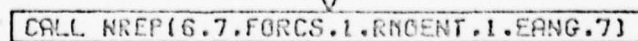
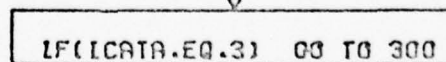
39

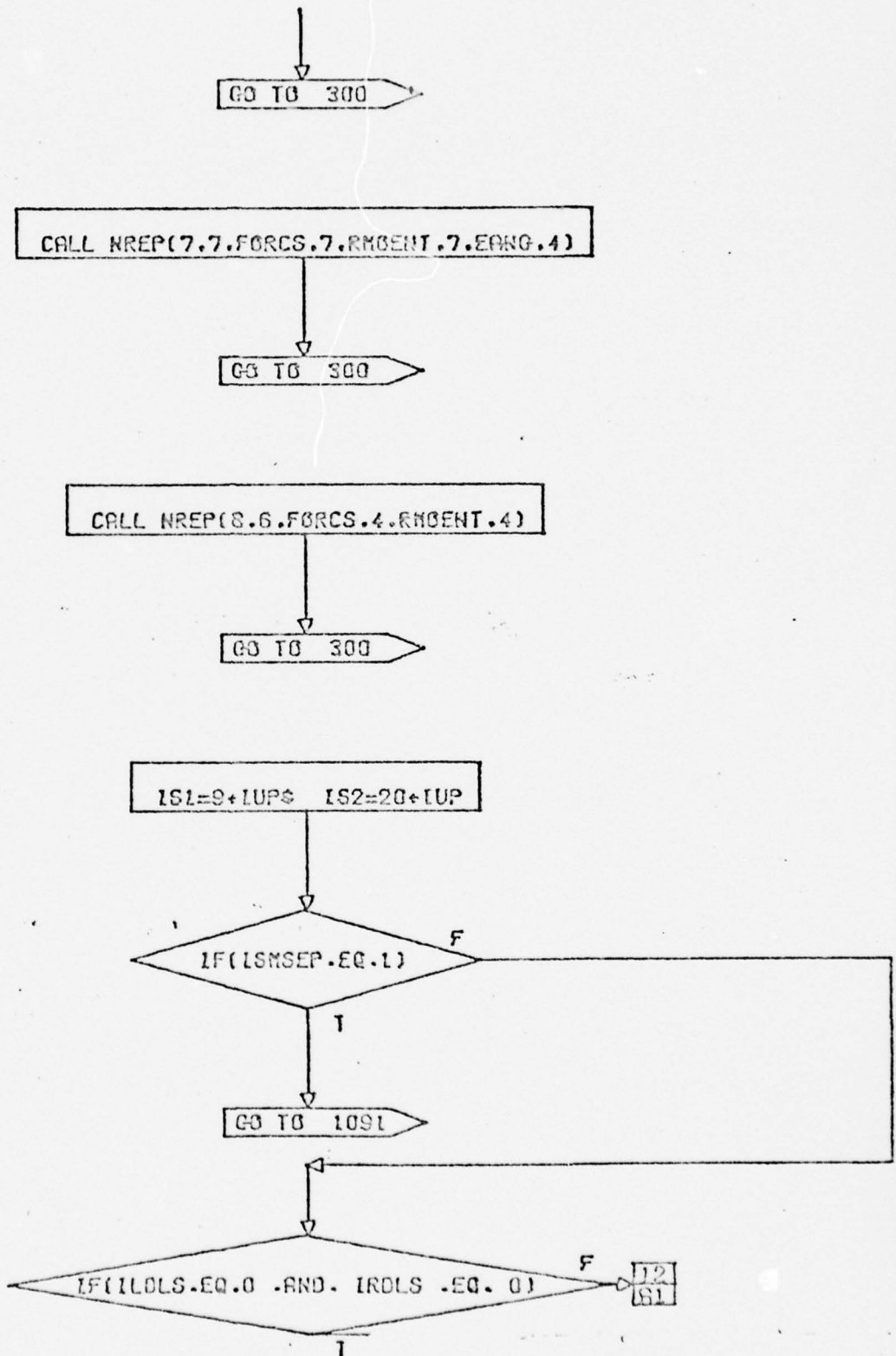






39







GO TO 1092

CALL NREP(9.7.WORK.IS1.WORK.IS2.FORCS.13)

A1

GO TO 300

IF(STNCEL .EQ. 1. .AND. ISMSEP .NE. 0) GO TO 300

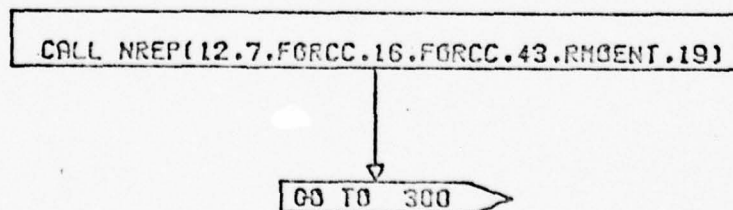
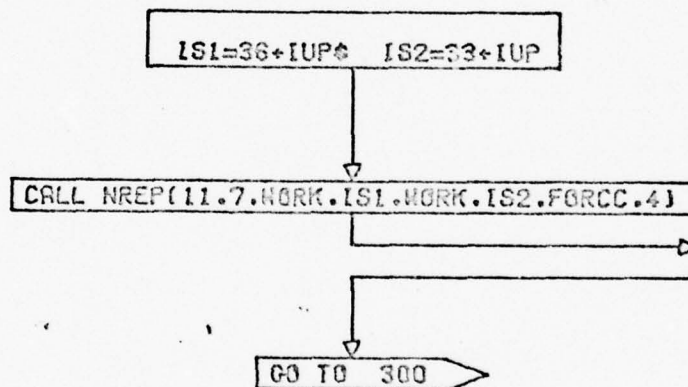
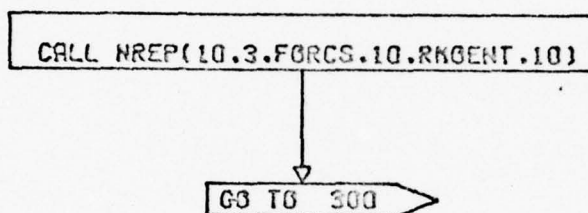
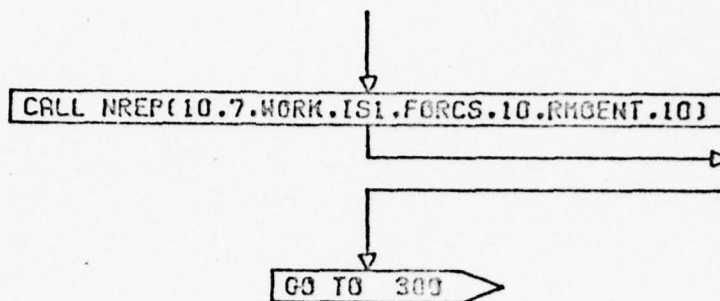
CALL NREP(9.3.WORK.IS2.FORCS.13)

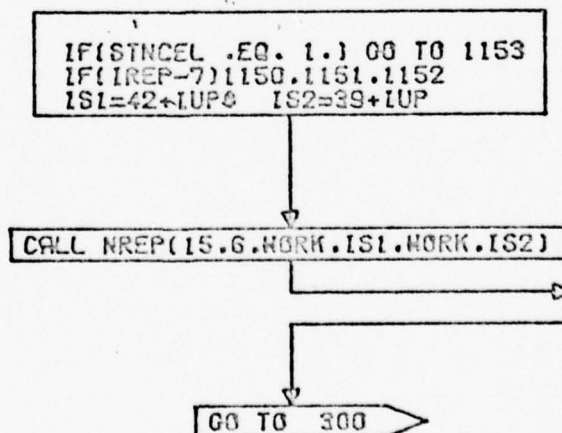
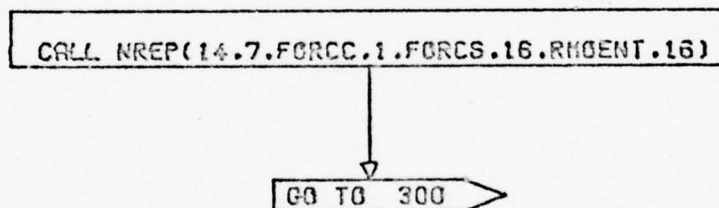
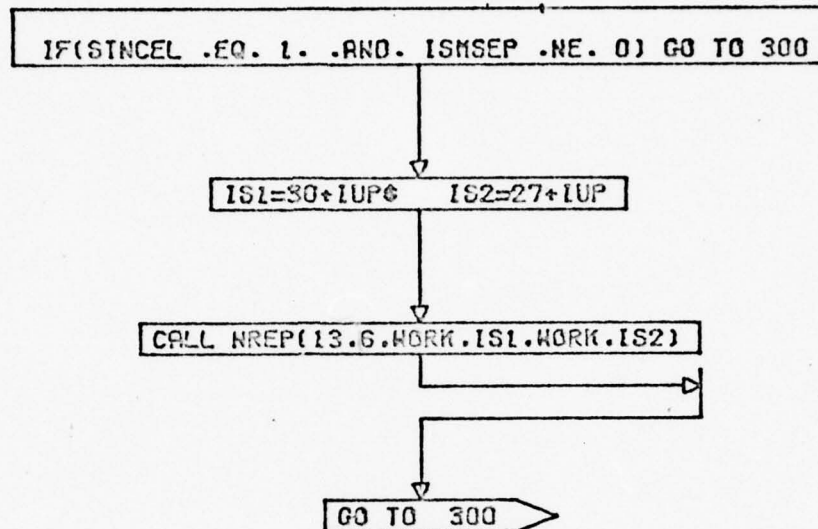
GO TO 300

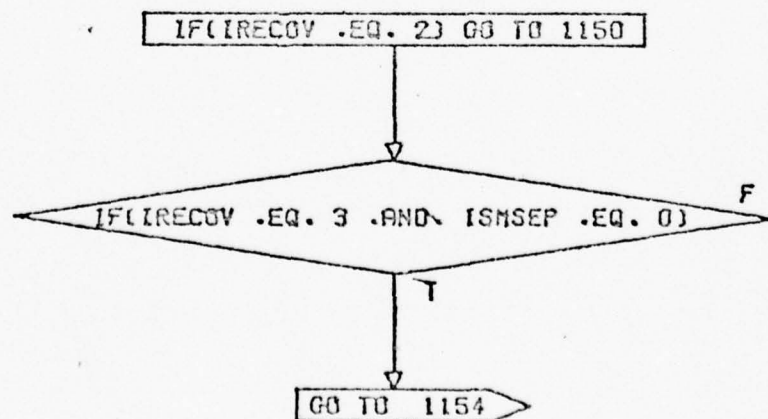
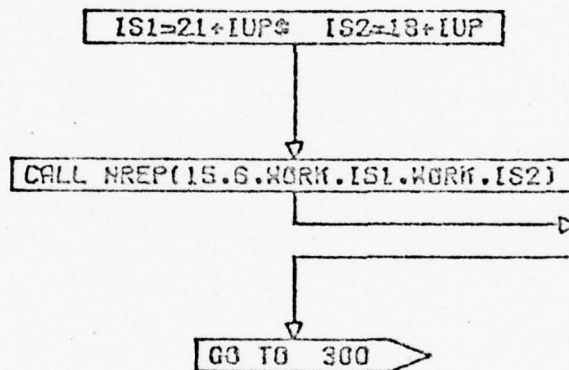
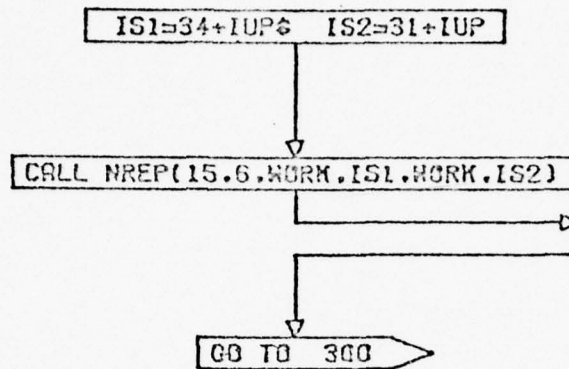
CALL NREP(9.6.WORK.IS1.WORK.IS2)

GO TO 300

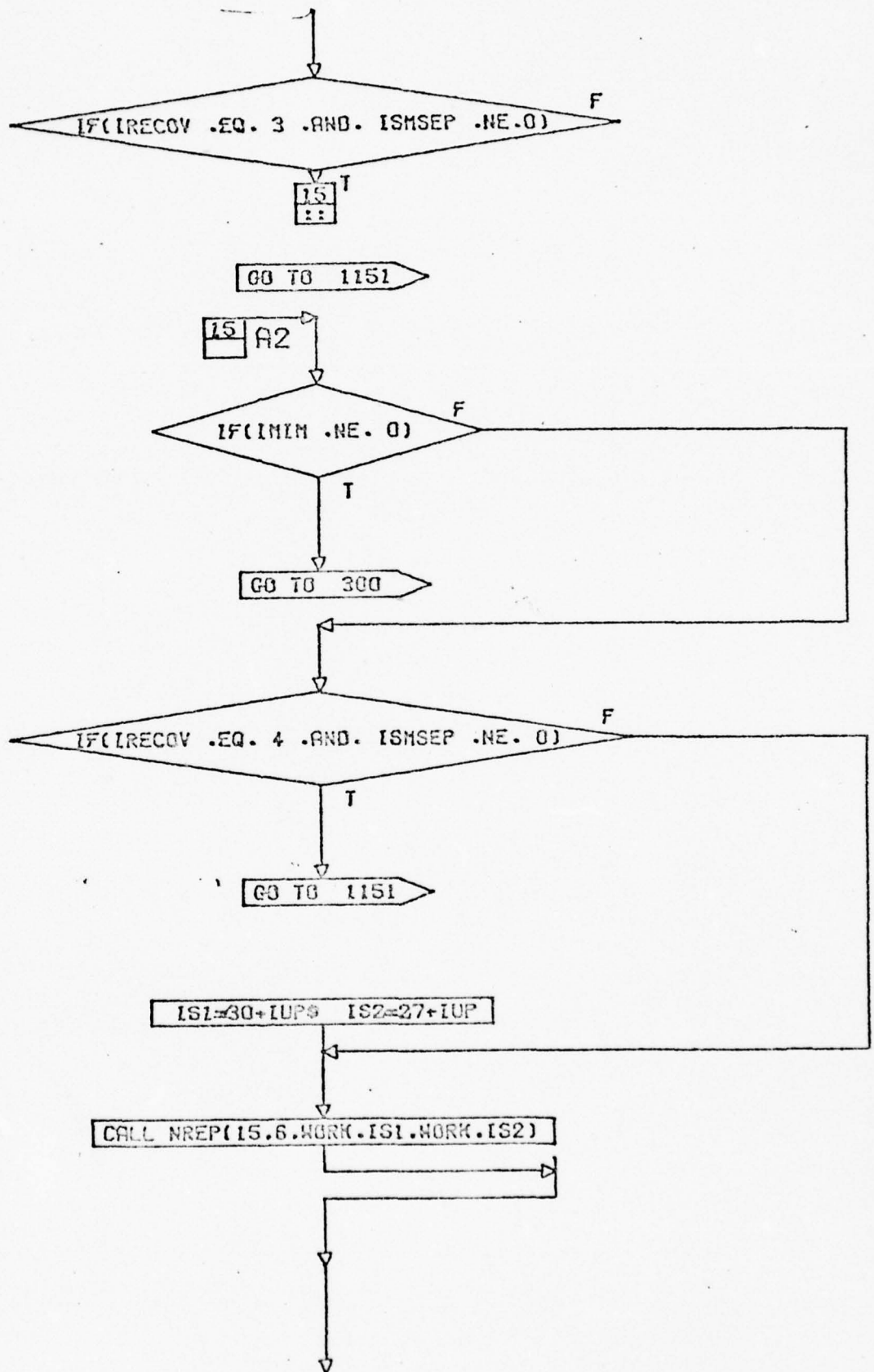
IF(IREP-6)1102.1102.1101  
IF(STNCEL .EQ. 1. .AND. ISMSEP .NE. 0) GO TO 1101  
IS1=14+IUP











GO TO 300

CALL NREP(16.6.FORCS.22.RHOENT.22)

GO TO 300

CALL NREP(17.6.FORCS.25.RHOENT.25)

GO TO 300

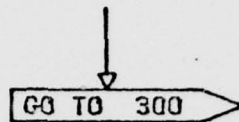
ZACC = ZACC/386.088

CALL NREP(18.8.ORI.1)

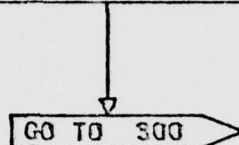
GO TO 300

CALL NREP(19.7.DXCON.1.XACCEL.1.TXFRCE.1)

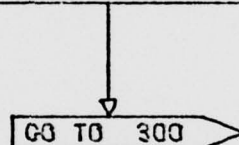
CONT. ON PG 18



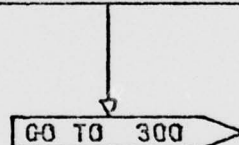
CALL NREP(20.6.FMMA.1.FMMA.4)



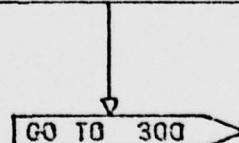
CALL NREP(21.7.FMMA.10.FMMA.13.RUCK.64)



CALL NREP(22.6.FMMA.7.FMMA.16)



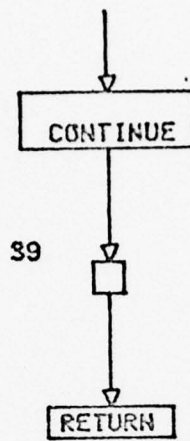
CALL NREP(23.7.RUCK.76.RUCK.79.RUCK.67)



39

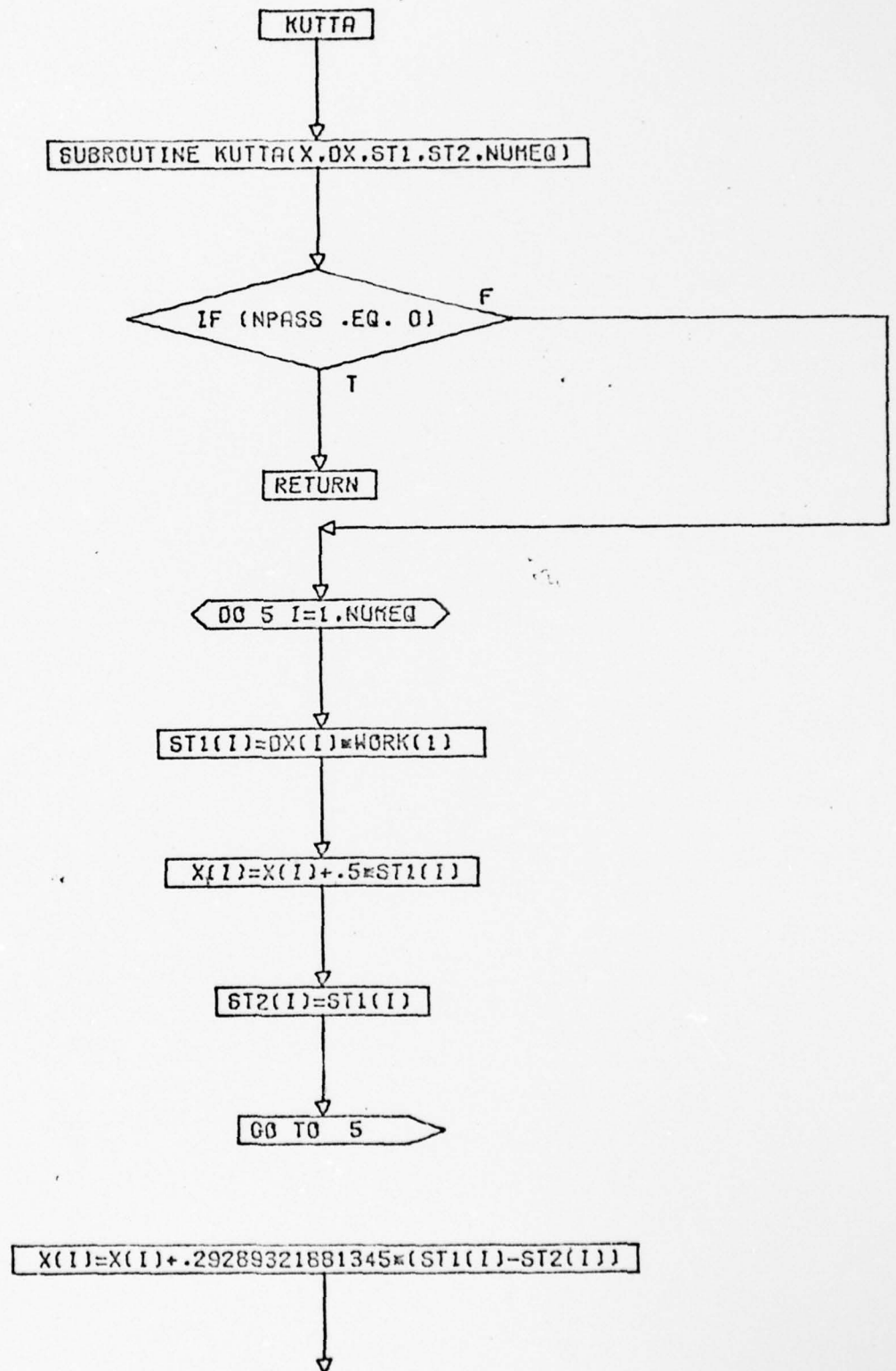


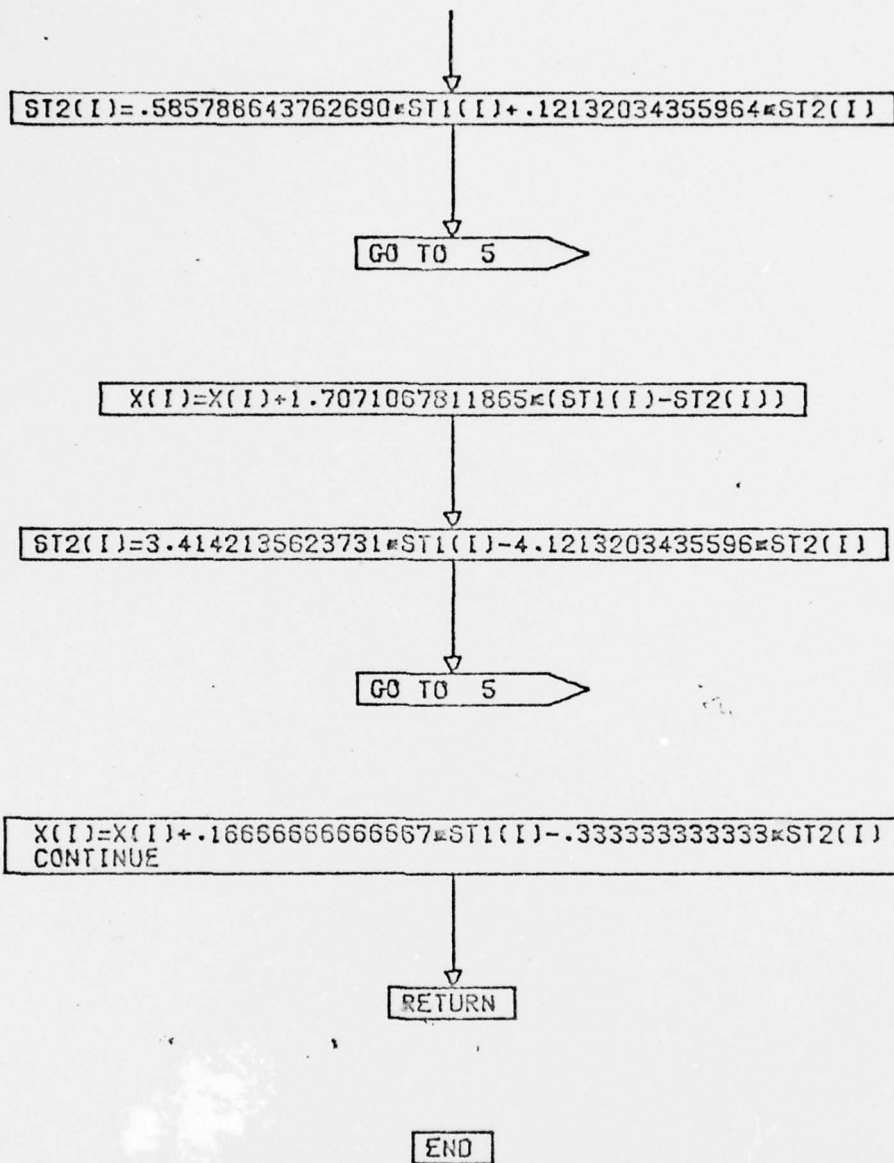
CONT. ON PG 19

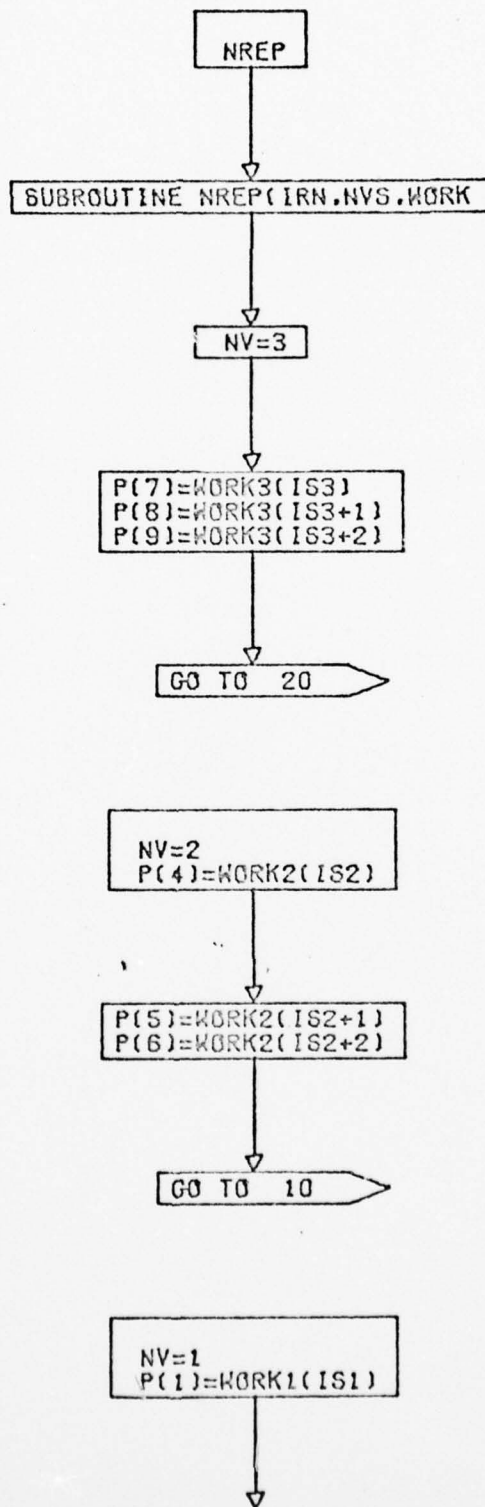


END

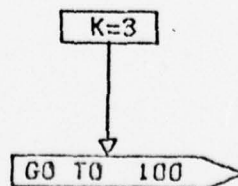
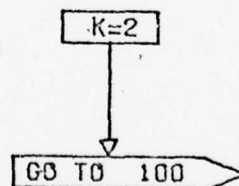
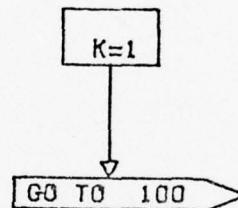
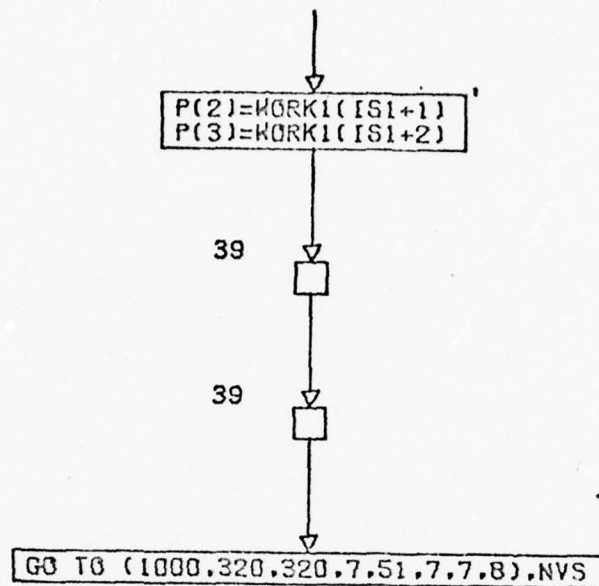




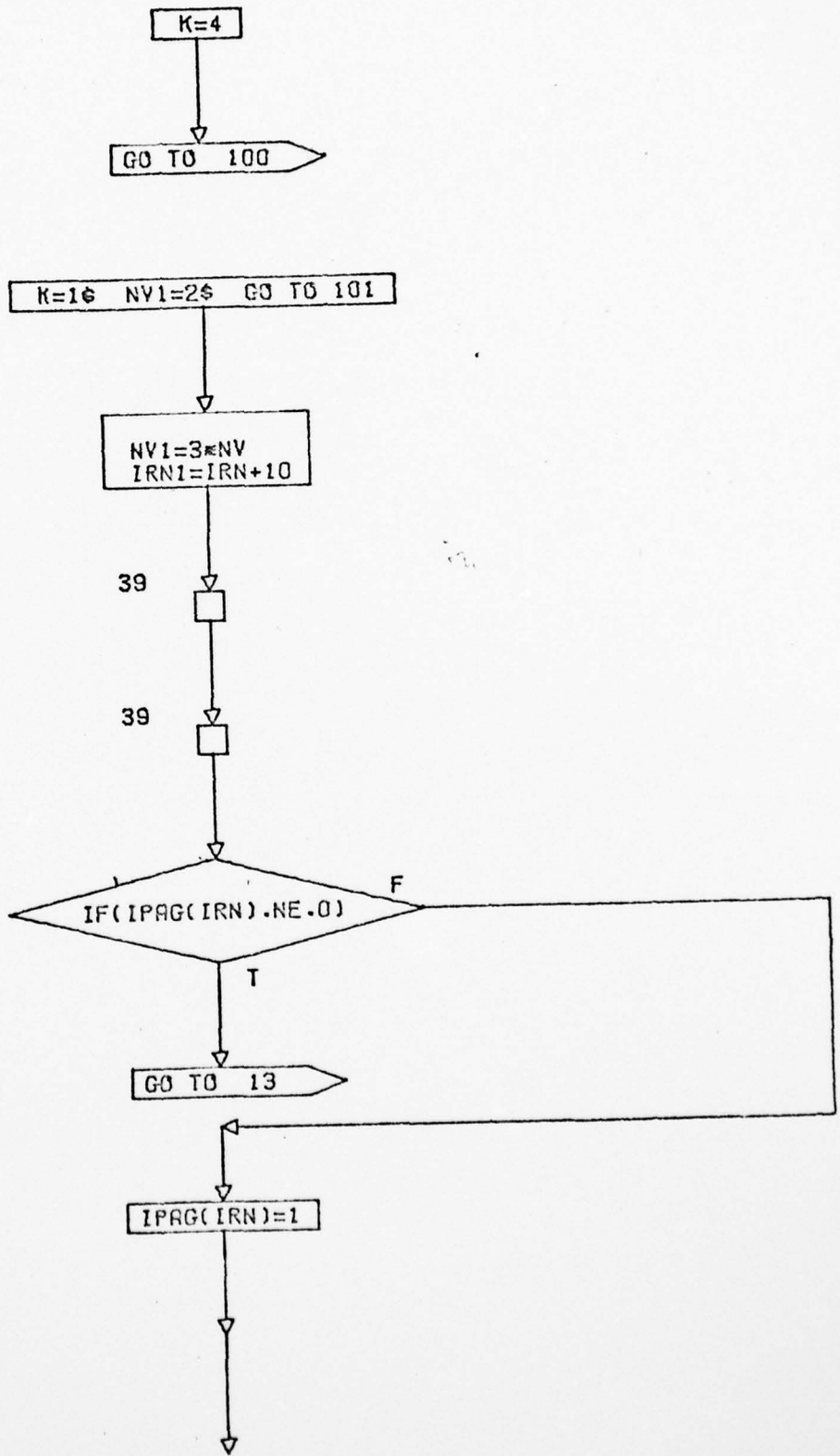




CONT. ON PG 2







WRITE(IRN1,803) (PROBDS(I),I=1,8),IPAG(IRN)

WRITE(IRN1,804) WHEN,IRN  
FORMAT(1H ,38X,5HDATE: ,A10,4X,7HREPORT( ,12,3H): )

WRITE(IRN1,JFMT(1,IRN))

GO TO 12

IF(ICOUNT(IRN)-52) 12,12,11

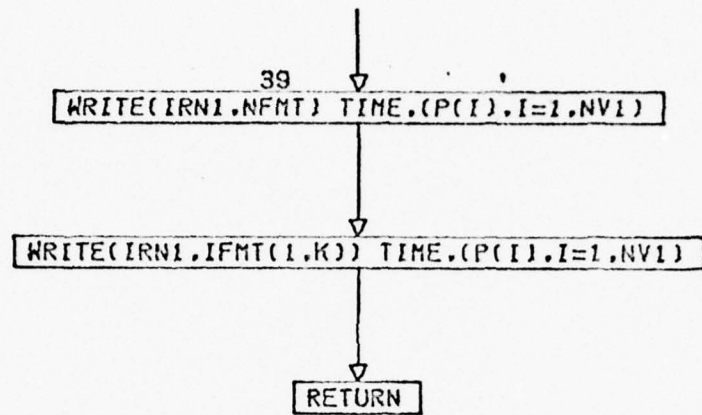
IPAG(IRN)=IPAG(IRN)+1

WRITE(IRN1,803) (PROBDS(I),I=1,8),IPAG(IRN)  
FORMAT(1H1,1H ,8A10,30X,=PAGE=,13,///)

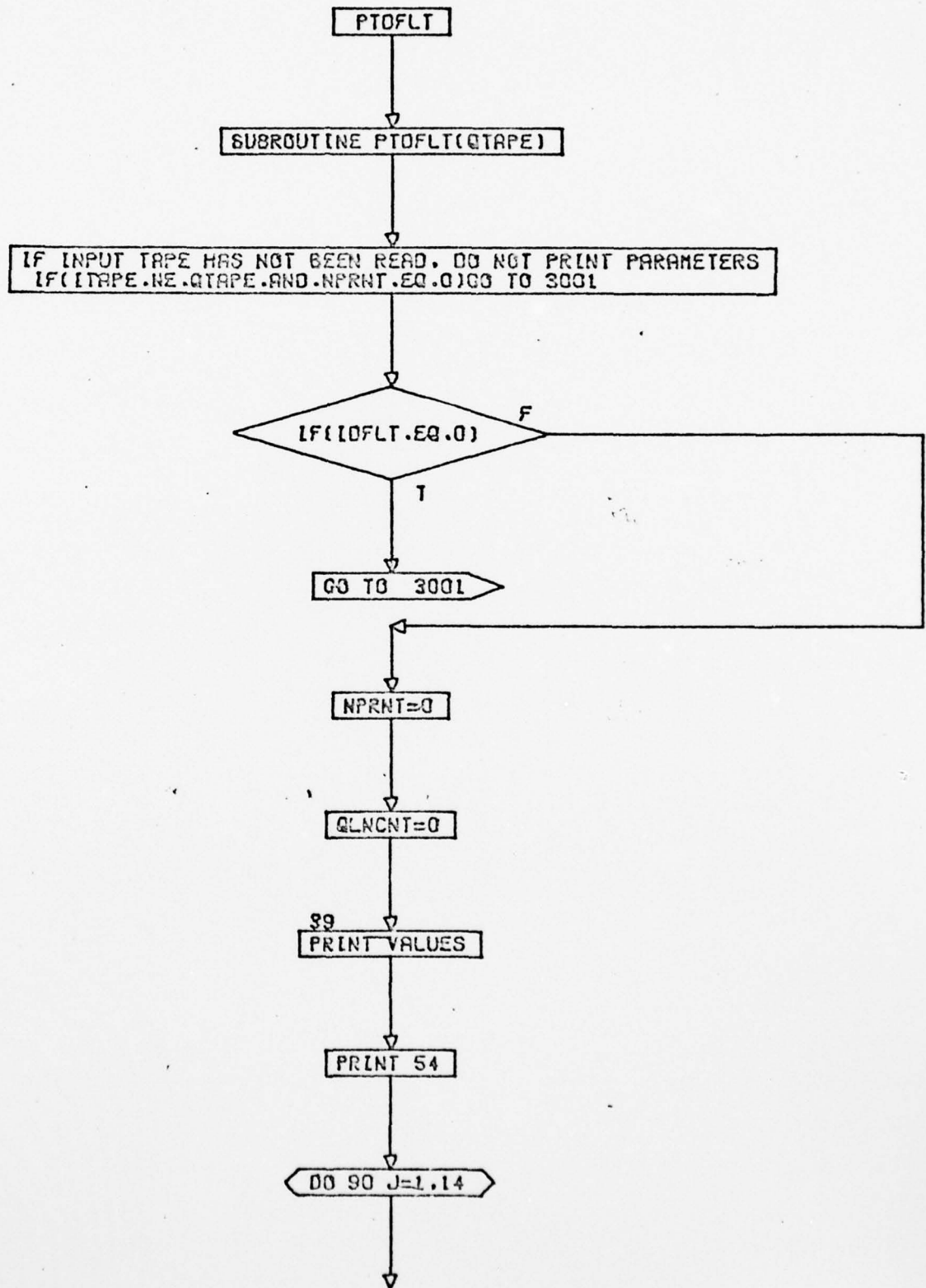
ICOUNT(IRN)=0  
WRITE(IRN1,804) WHEN,IRN  
WRITE(IRN1,JFMT(1,IRN))

ICOUNT(IRN)=ICOUNT(IRN)+1

CONT. ON PG 5

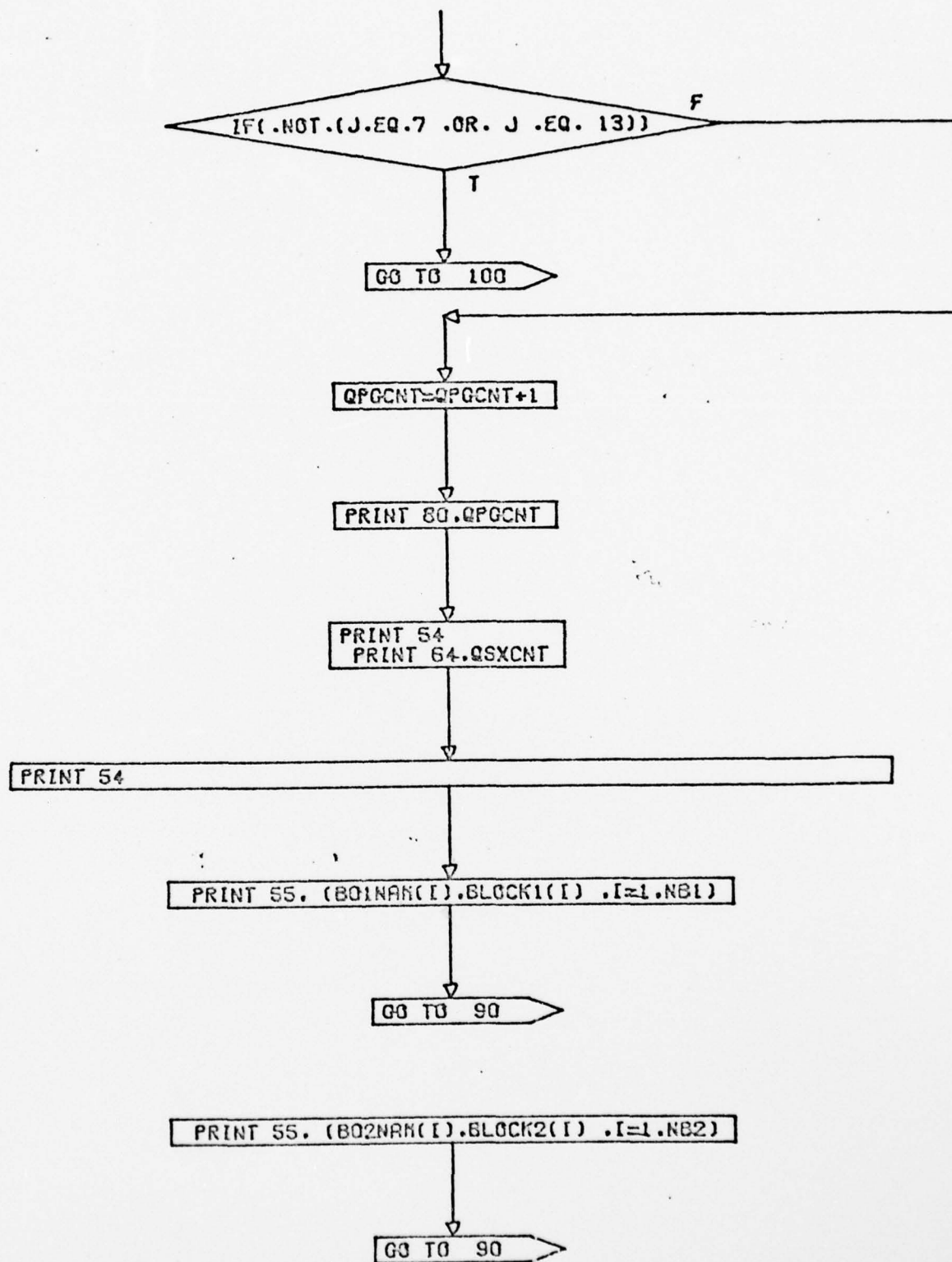


END



CONT. ON P9 2





PRINT 55. (B03NAM(I).BLOCK3(I) .I=1.NB3)

GO TO 90

PRINT 55. (B04NAM(I).BLOCK4(I) .I=1.NB4)

GO TO 90

PRINT 55. (B05NAM(I).BLOCK5(I) .I=1.NB5)

GO TO 90

PRINT 55. (B06NAM(I).BLOCK6(I) .I=1.NB6)

GO TO 90

PRINT 55. (B07NAM(I).BLOCK7(I) .I=1.NB7)

GO TO 90

PRINT 55. (B08NAM(I).BLOCK8(I).I=1.NB8)

GO TO 90

PRINT 55. (B09NAM(I).BLOCK9(I).I=1.NB9)

GO TO 90

PRINT 55. (B10NAM(I).BLOCK10(I).I=1.NB10)

GO TO 90

PRINT 55. (B11NAM(I).BLOCK11(I).I=1.NB11)

GO TO 90

PRINT 55. (B12NAM(I).BLOCK12(I).I=1.NB12)

GO TO 90

PRINT 55.(B13NAM(I).BLOCK13(I).I=1.NB13)

GO TO 90

PRINT 55.(B14NAM(I).BLOCK14(I).I=1.NB14)

GO TO 85

QSCNT = QSCNT + 1  
QPCNT = QPCNT + 1

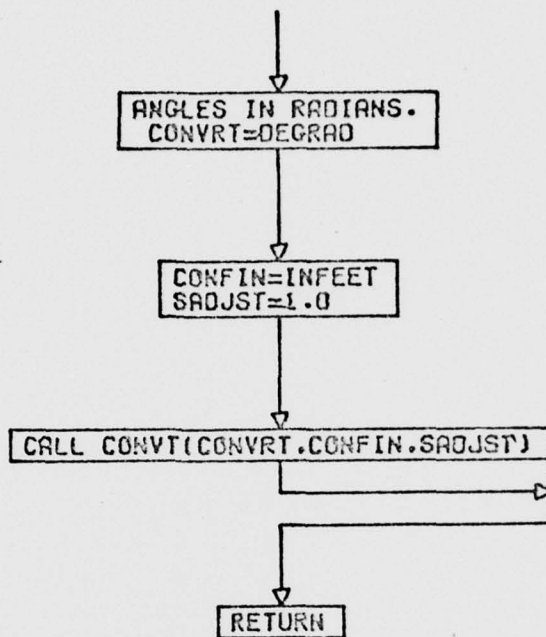
PRINT 80.QPCNT  
PRINT 55

39  
PRINT THE CONTROL WORDS

PRINT 57.(INTNAM(I).INT(I).I=1.NIN)

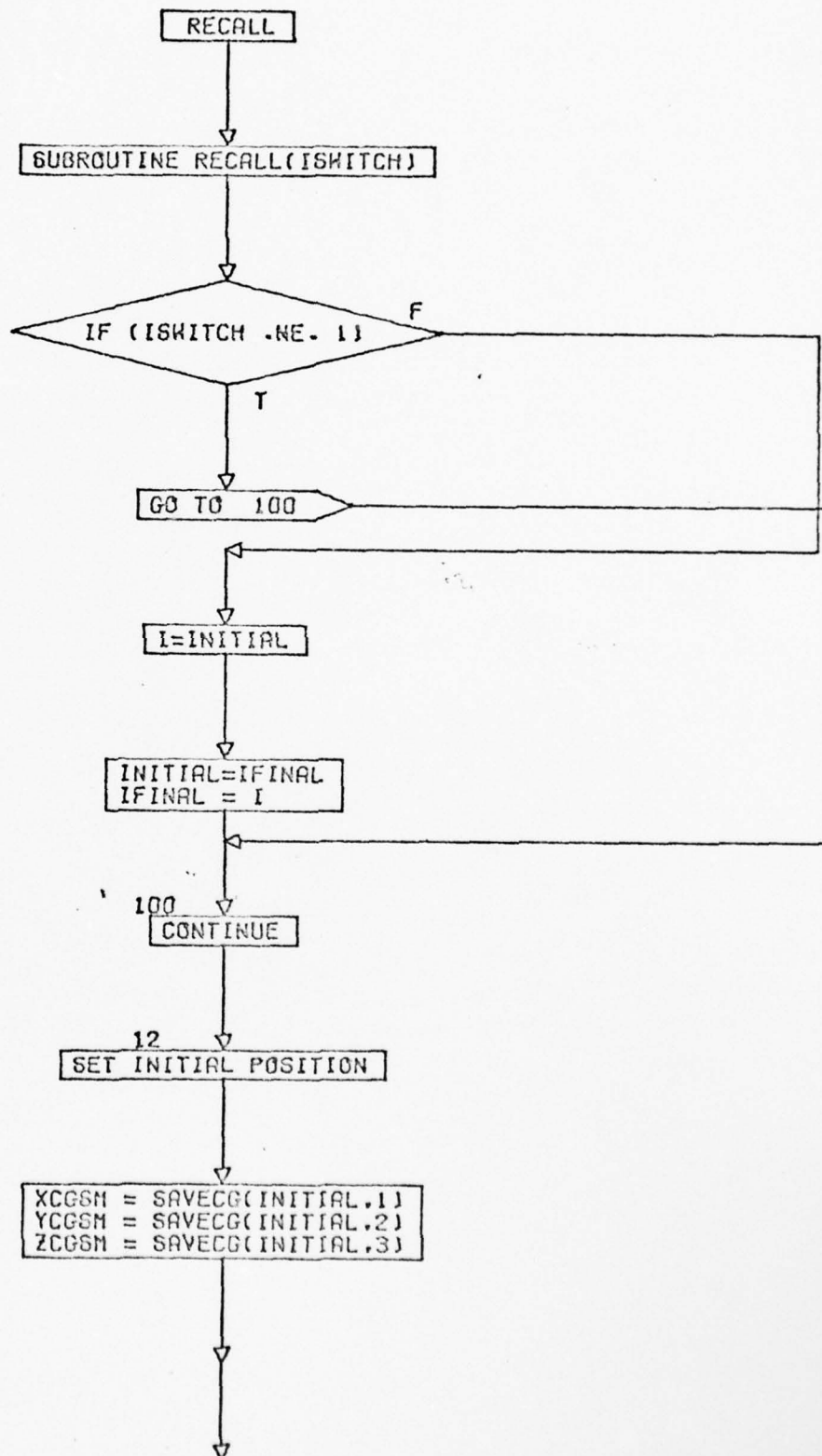
39  
\*\*\*\*\* PARAMETERS AND CONTROL WORDS ARE PRINTED\*\*\*\*\*

39  
CONVERT ALL PARAMETERS CONTAINING ANGLES IN DEGREES TO

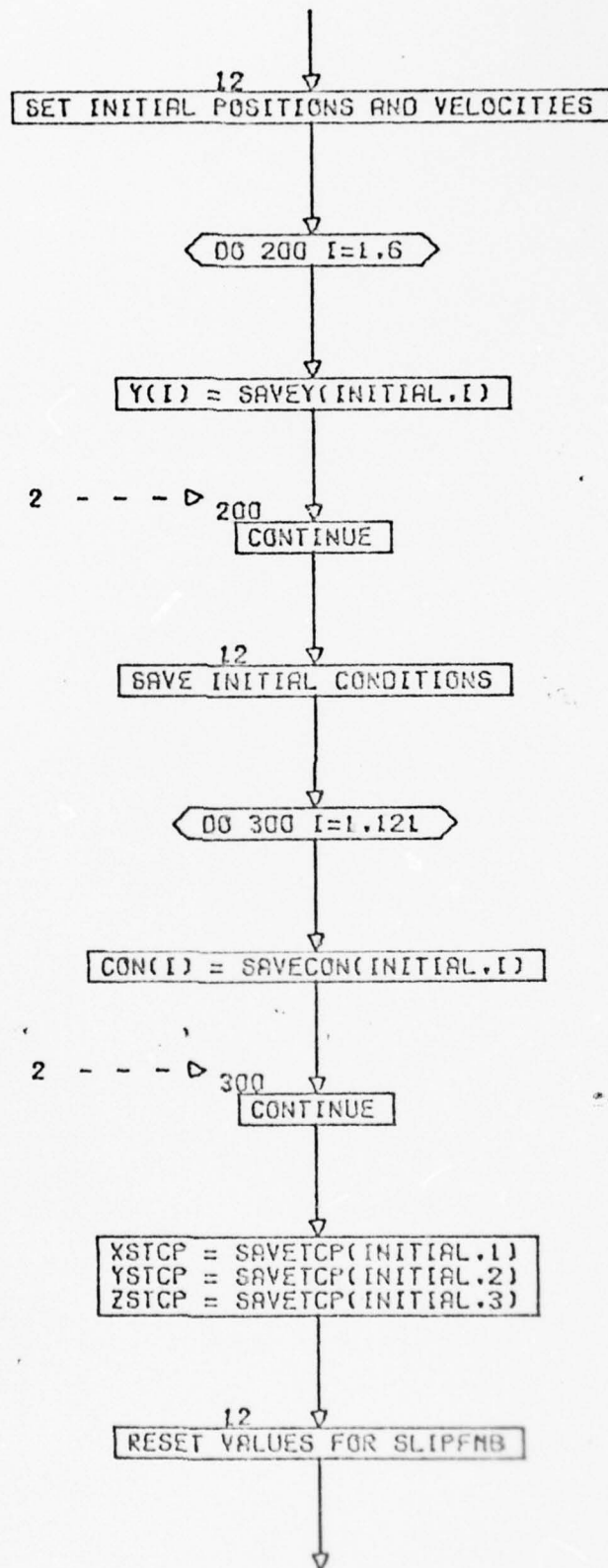


END





CONT. ON PG 2



AD-A047 954

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NL

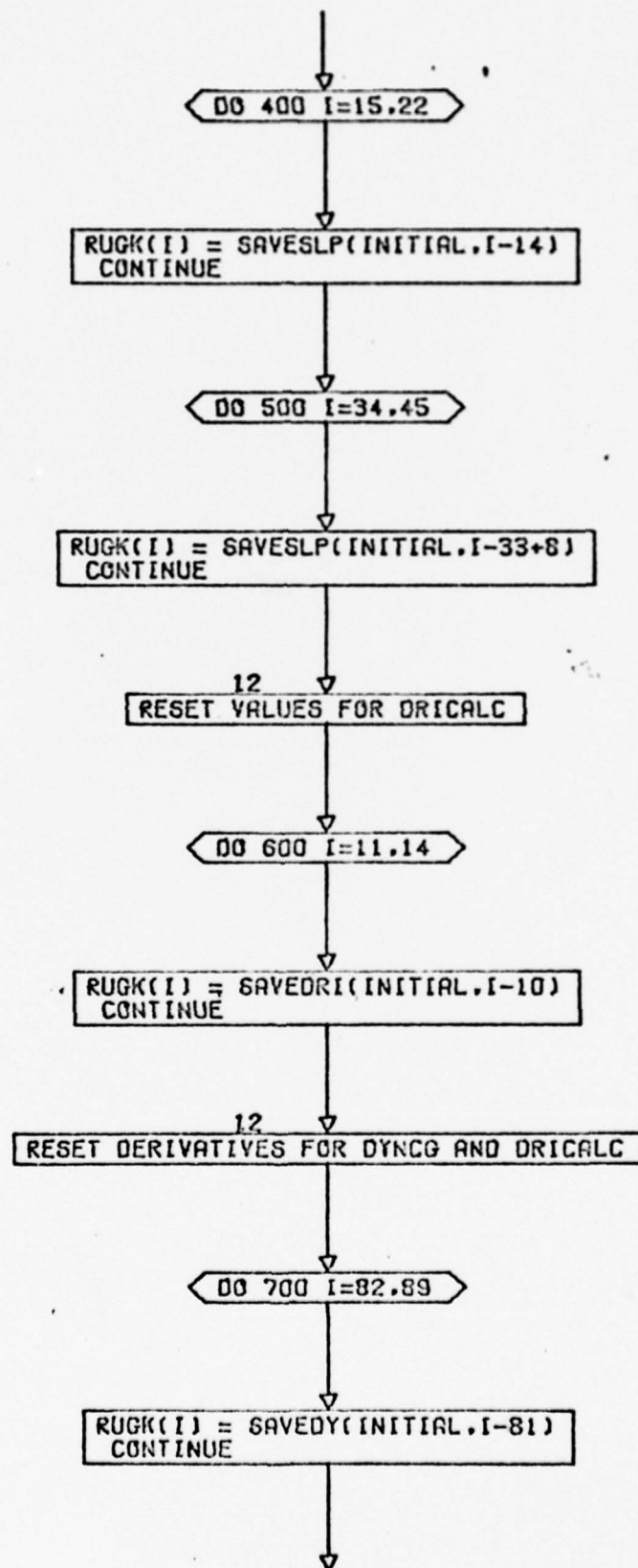
2 OF 2  
AD  
A047954



END  
DATE  
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1- 78

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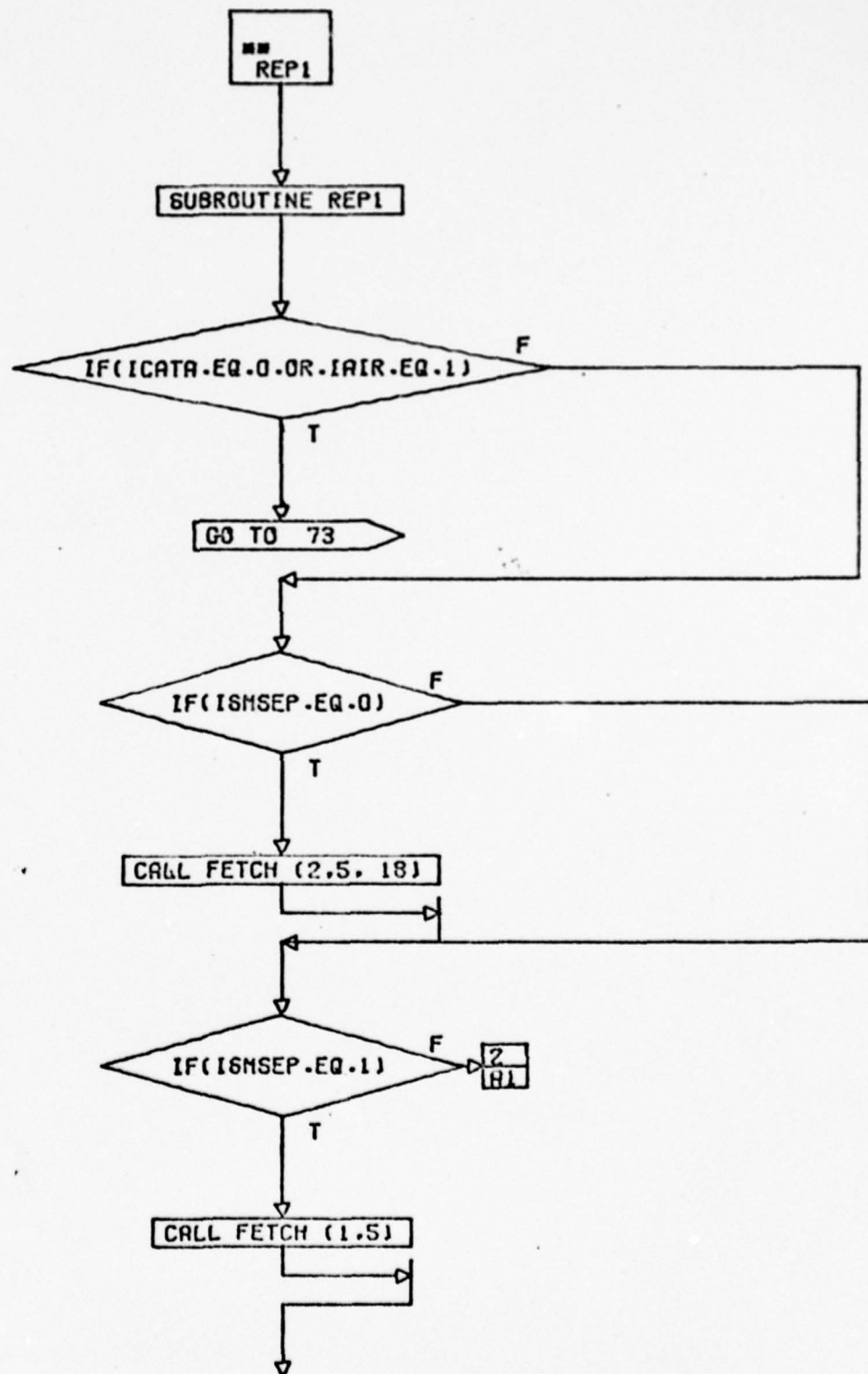
↓  
WRITE(11,1000) ISWITCH,SAVECG(INITIAL,1),INITIAL,IFINAL  
FORMAT(1H0.5X,6HRECALL.5X,8HISWITCH=,I3,3X,6HXCOSM=,E14.5,

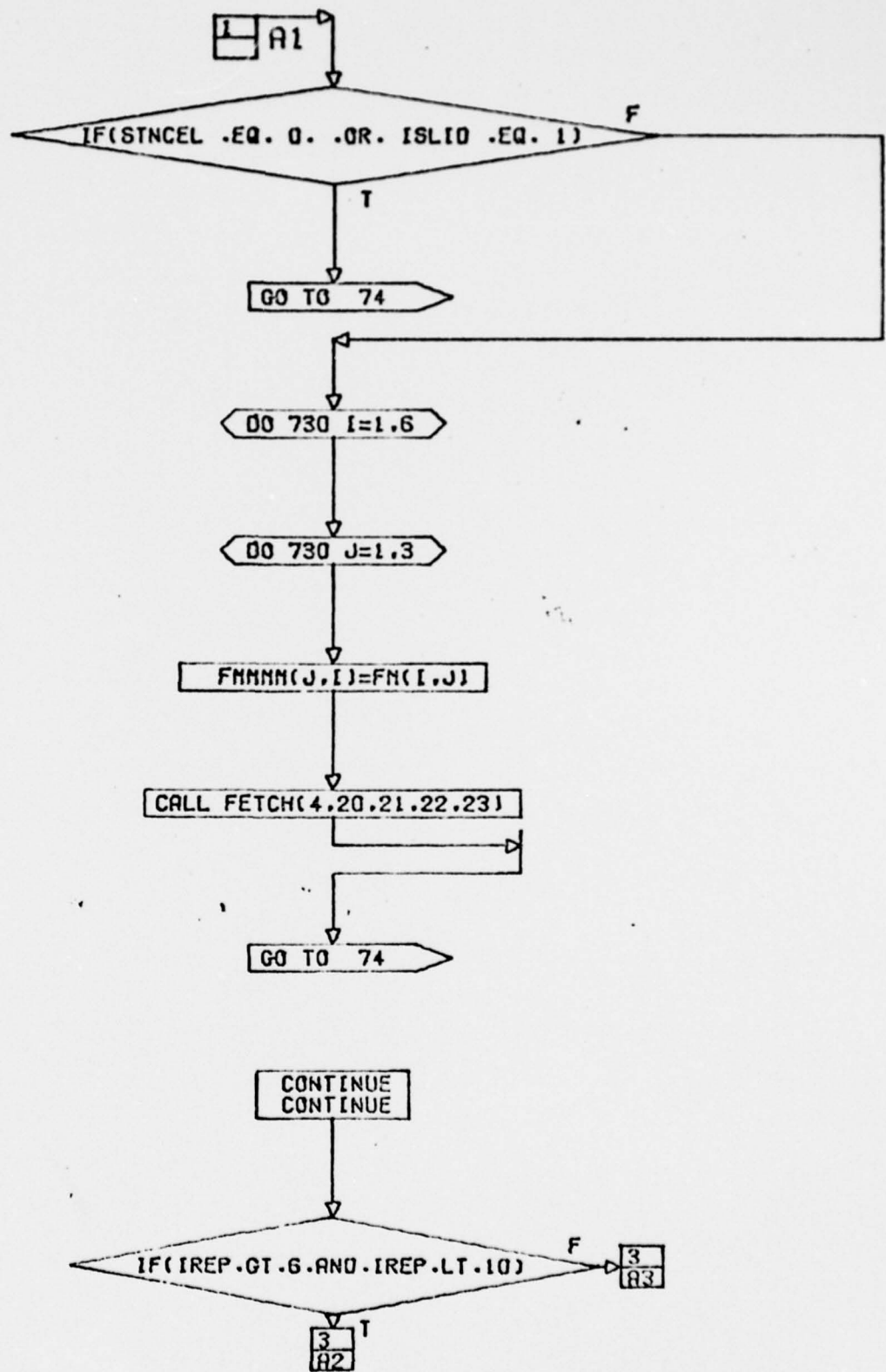
↓  
1 3X,8HINITIAL=,I3,3X,7HIFINAL=,I3)

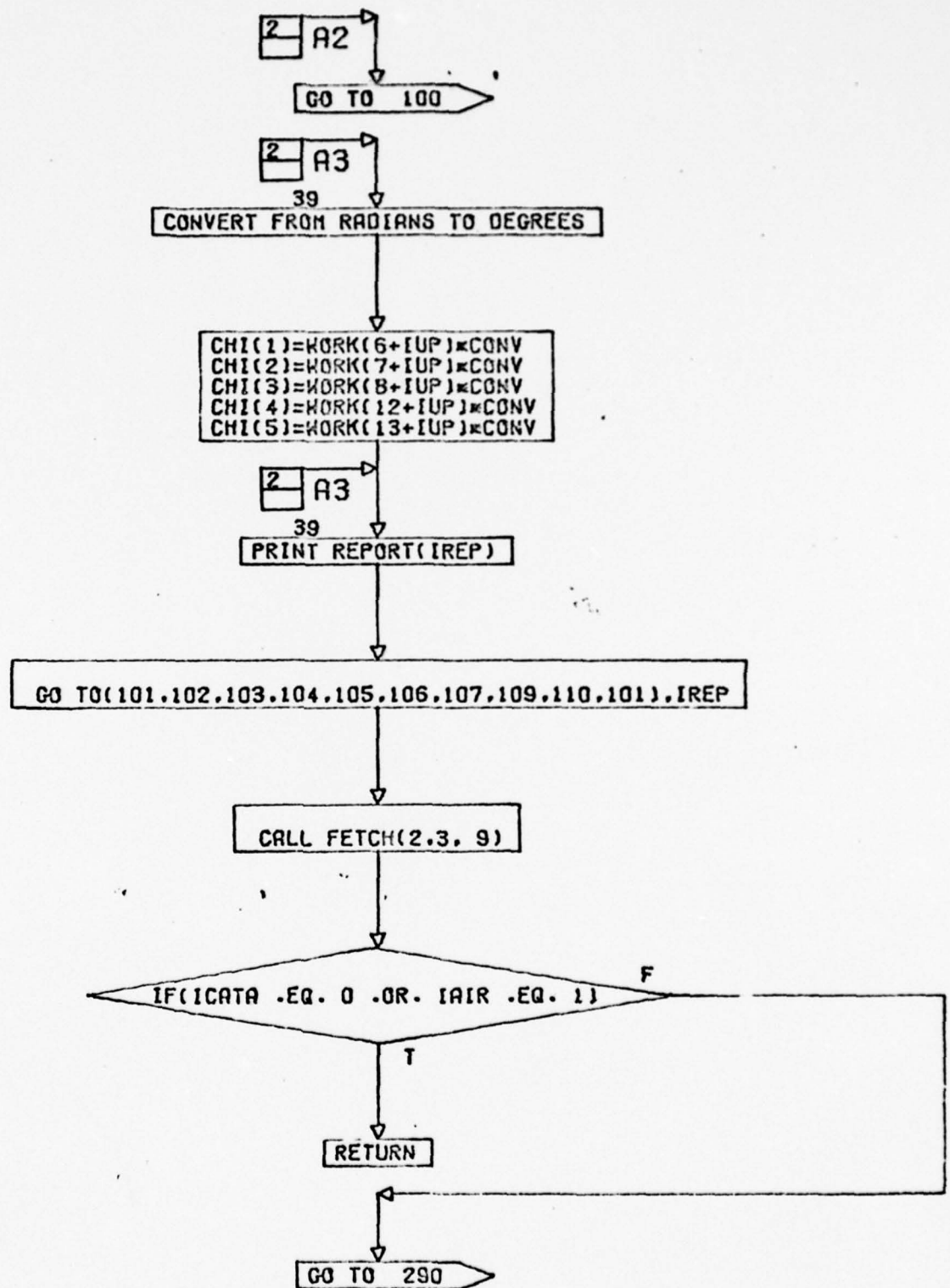
↓  
RETURN

END









CALL FETCH(4.2.3.4.9)

GO TO 290

CALL FETCH(5. 2.3.4. 9.13)

GO TO 290

CALL FETCH(6.2.3.4. 9.11.13)

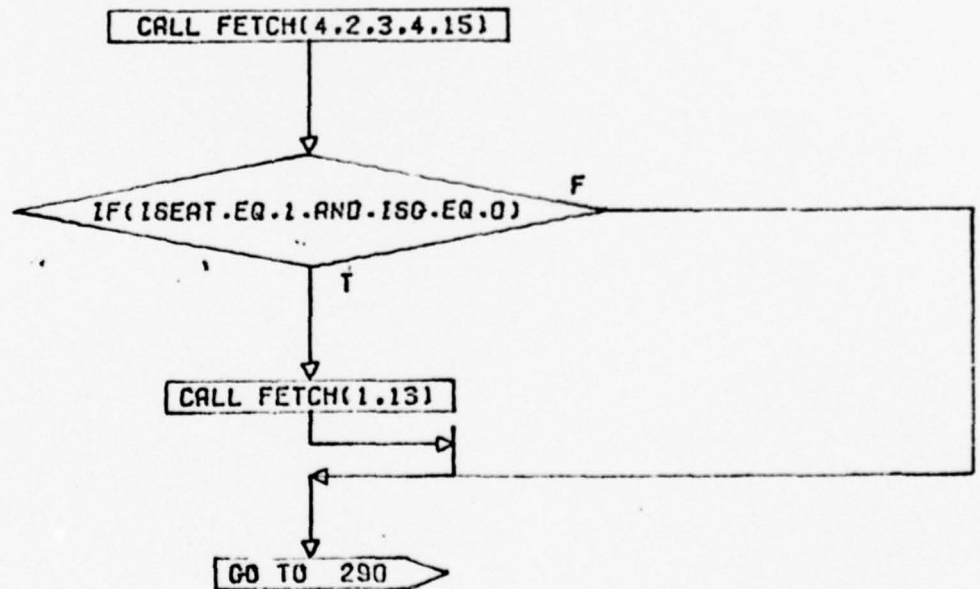
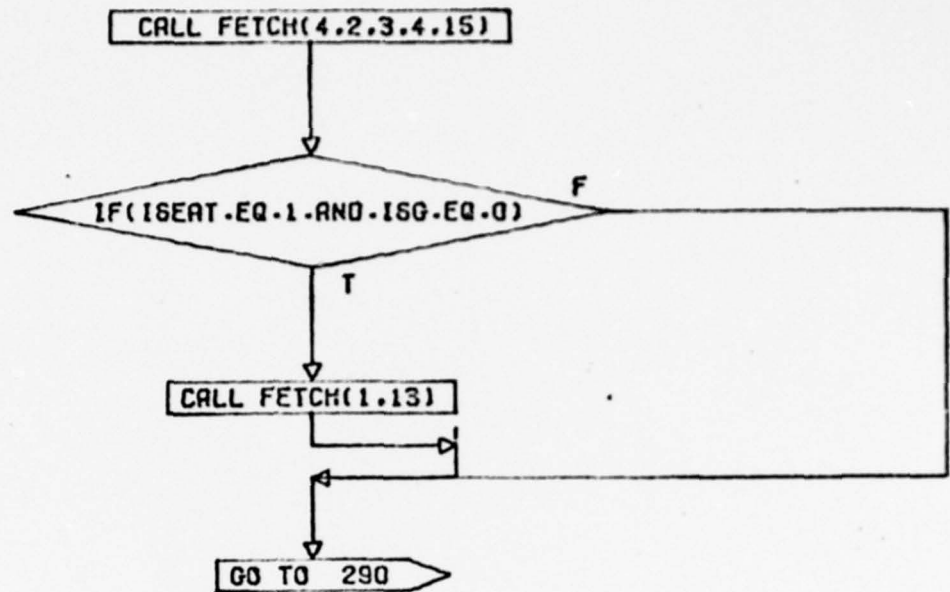
GO TO 290

CALL FE (7.2.3.4. 9.11.13.15)

GO TO 290

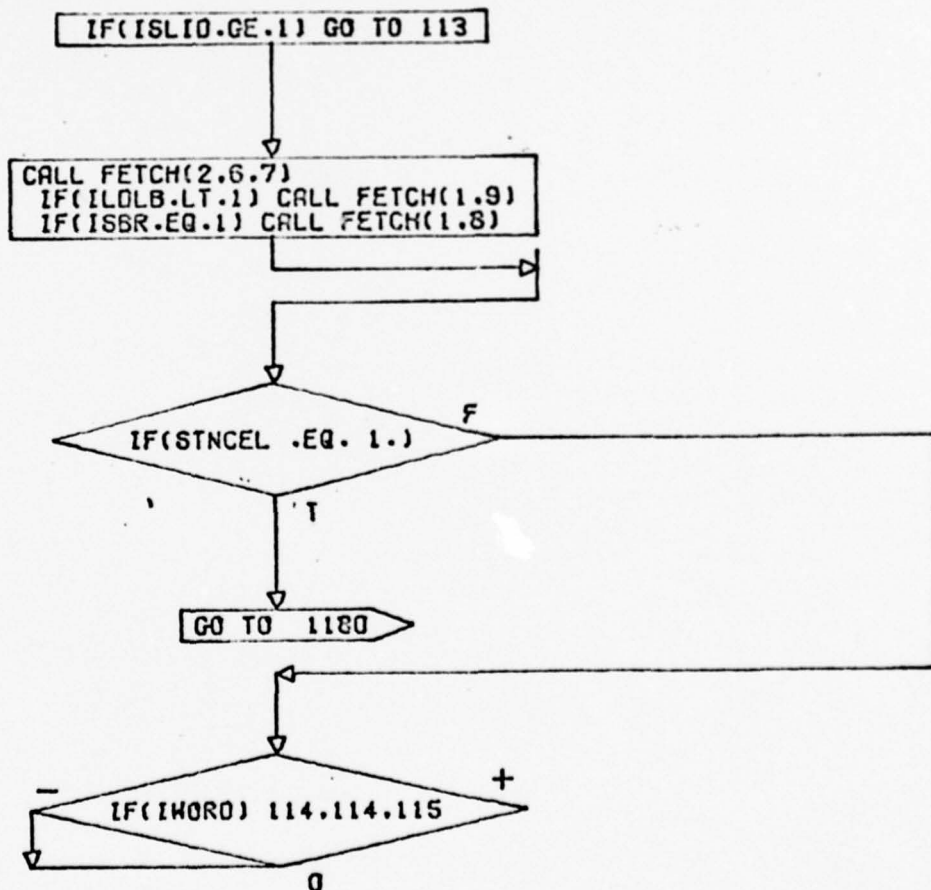
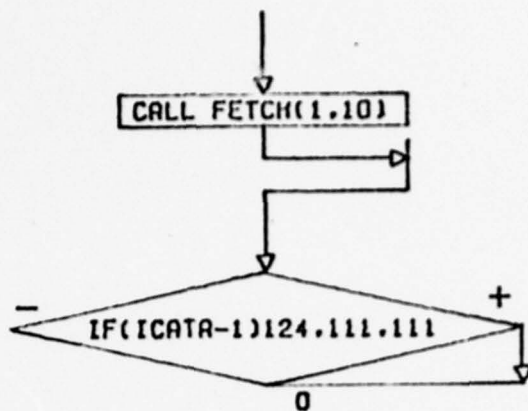
CALL FETCH(5. 2.3.4. 9.15)

GO TO 290



CALL FETCH(2,2,4)  
CONTINUE





CALL FETCH(1.14)

GO TO 125

IF(IWORD-1)125.117.117  
IF(ISO-1) 118.119.125  
CALL FETCH(2.11.12)  
IF(IRECOV -2) 1181.1182.1182  
CALL FETCH(1.14)\* GO TO 125  
CALL FETCH(1.15)  
IF(ISMSEP)120.120.121  
CALL FETCH(1.16)

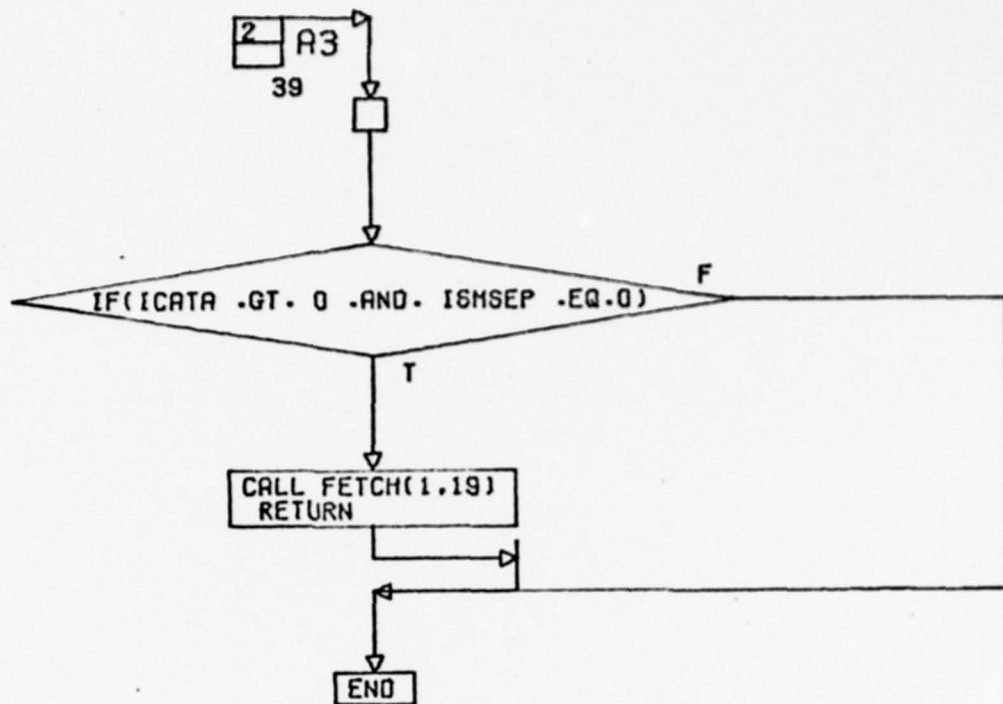
GO TO 125

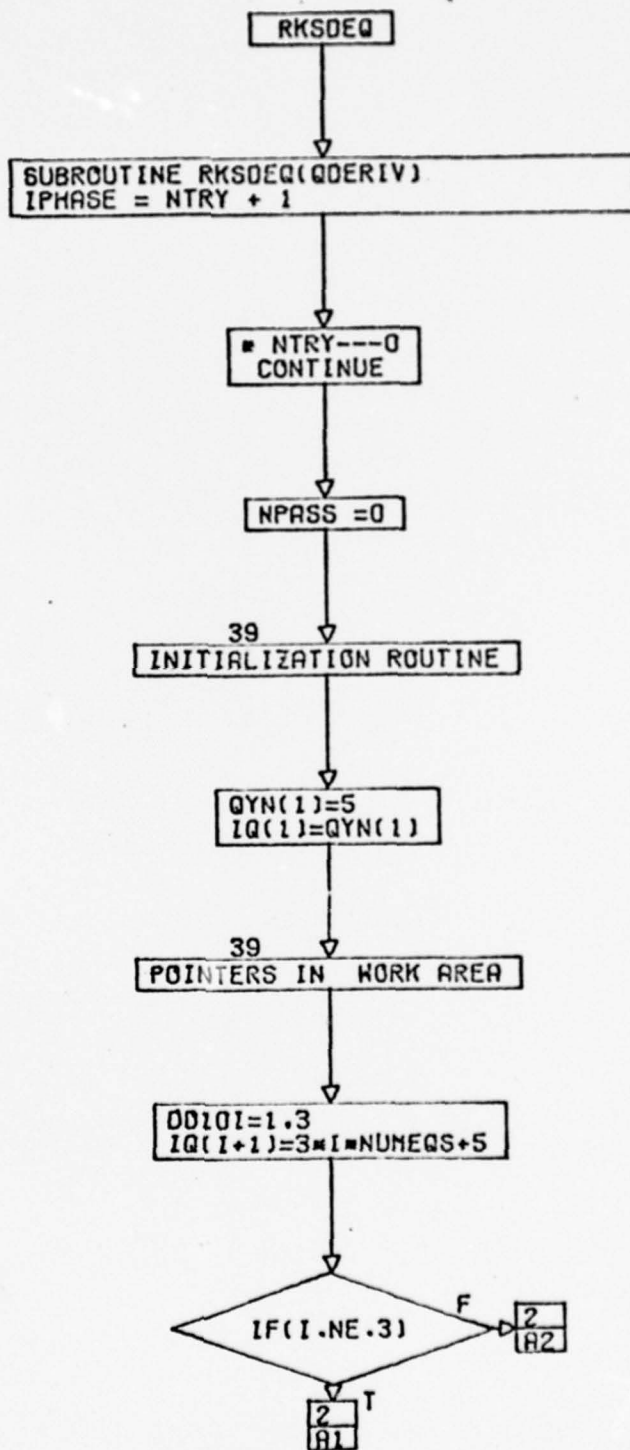
CALL FETCH(1.17)

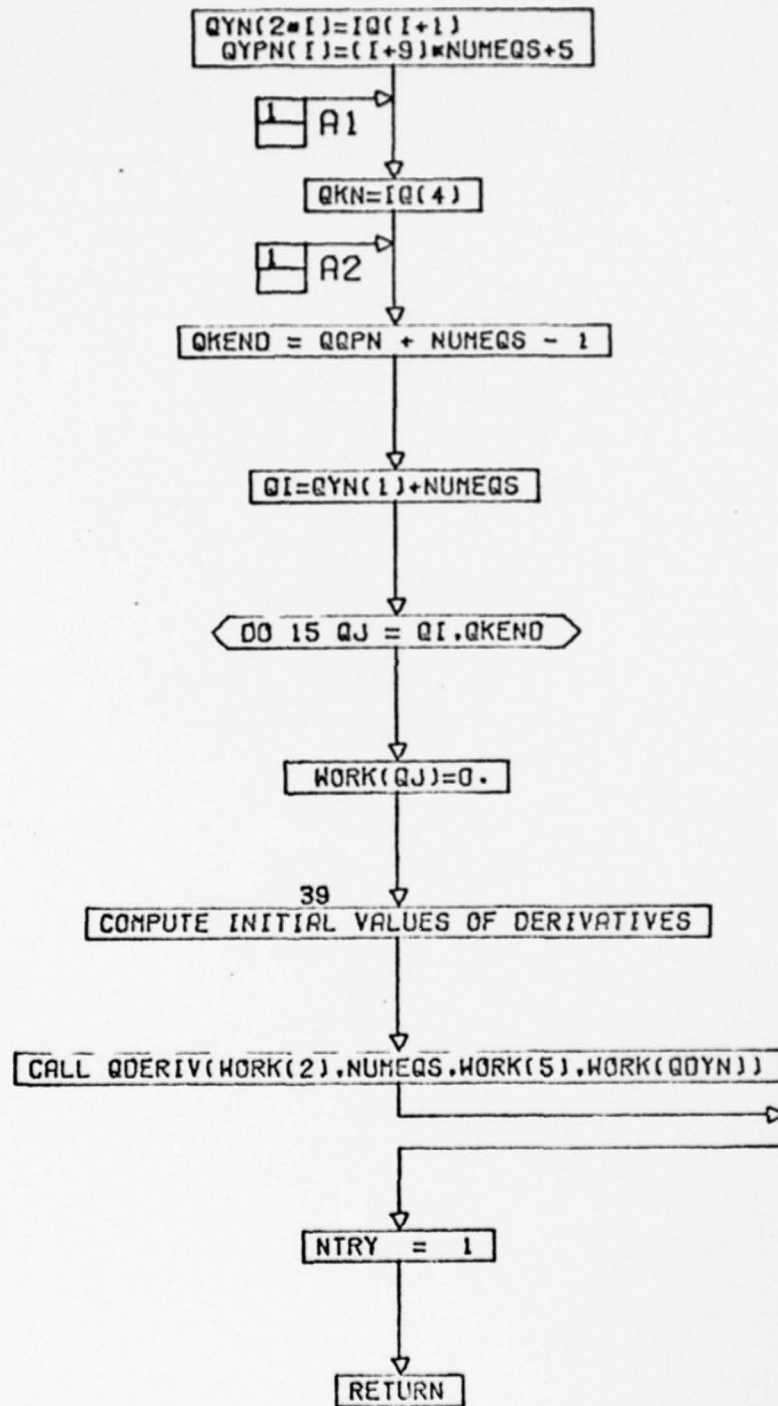
GO TO 125

CONTINUE

CONTINUE









CONTINUE WITH INTEGRATION  
NTRY---1  
CONTINUE

39  
MOVE TIME VALUES

WORK(4) = WORK(3)  
WORK(3) = WORK(2)

DO 110 I=1,3

$M = (I-1) \times 3 \times \text{NUMEQS} + 5$   
 $J = M + \text{NUMEQS}$   
 $L = M + 2 \times \text{NUMEQS}$

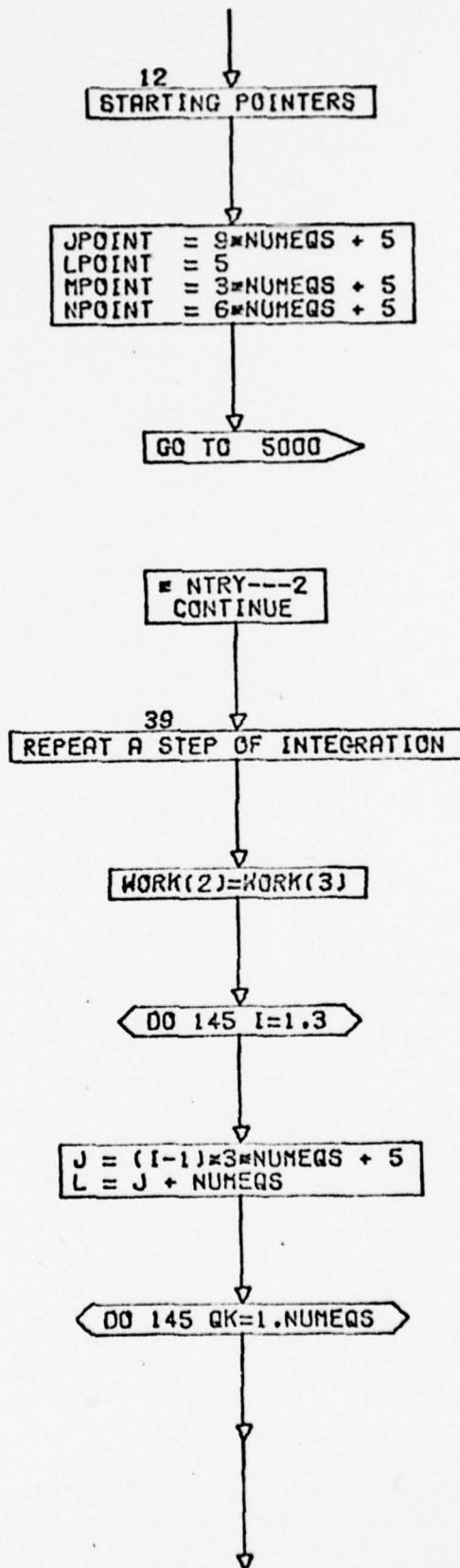
DO 110 QK = 1, NUMEQS

WORK(L) = WORK(J)  
WORK(J) = WORK(M)  
M = M + 1

J = J + 1  
L = L + 1

QSAVE = WORK(2)  
WORK(1) = DELTAT

CONT. ON PG 4



CONT. ON PG 5

↓  
WORK(J)=WORK(L)

↓  
J=J+1  
L=L+1

↓  
QSAVE = WORK(2)  
WORK(1) = DELTAT

↓  
12  
STARTING POINTERS

↓  
JPOINT = 9\*NUMEQS + 5  
LPOINT = 5  
MPOINT = 3\*NUMEQS + 5  
NPOINT = 6\*NUMEQS + 5

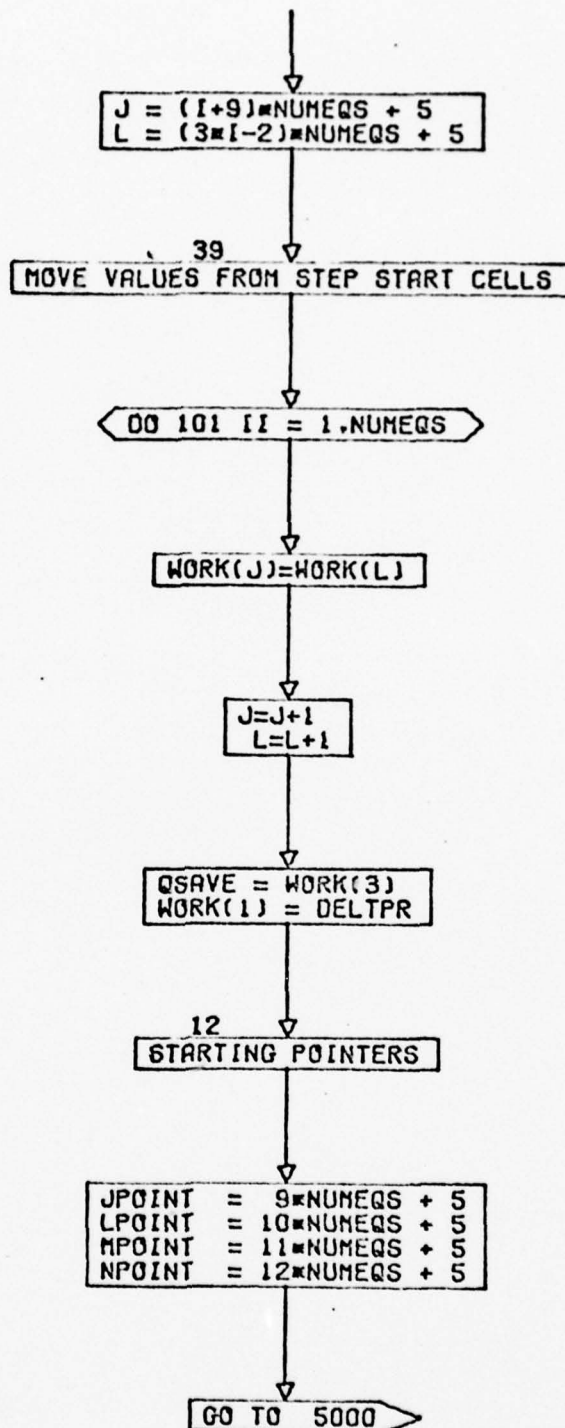
↓  
GO TO 5000

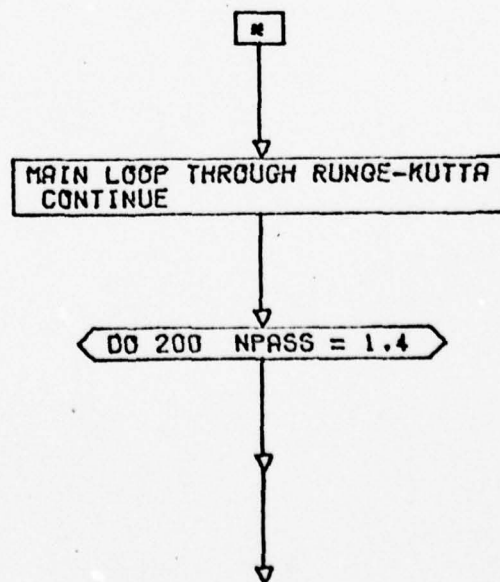
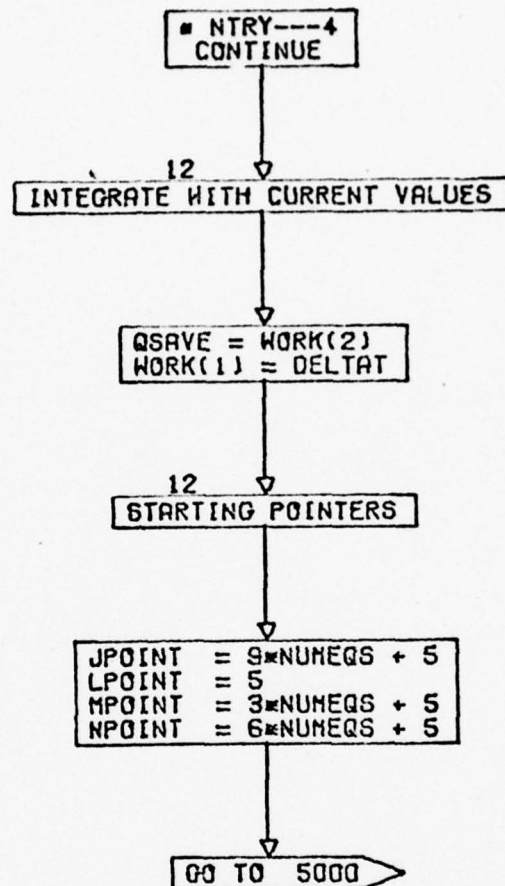
↓  
NTRY---3  
CONTINUE

↓  
39  
NTRY = 3 IS FOR A SPECIAL FIXED STEP SIZE

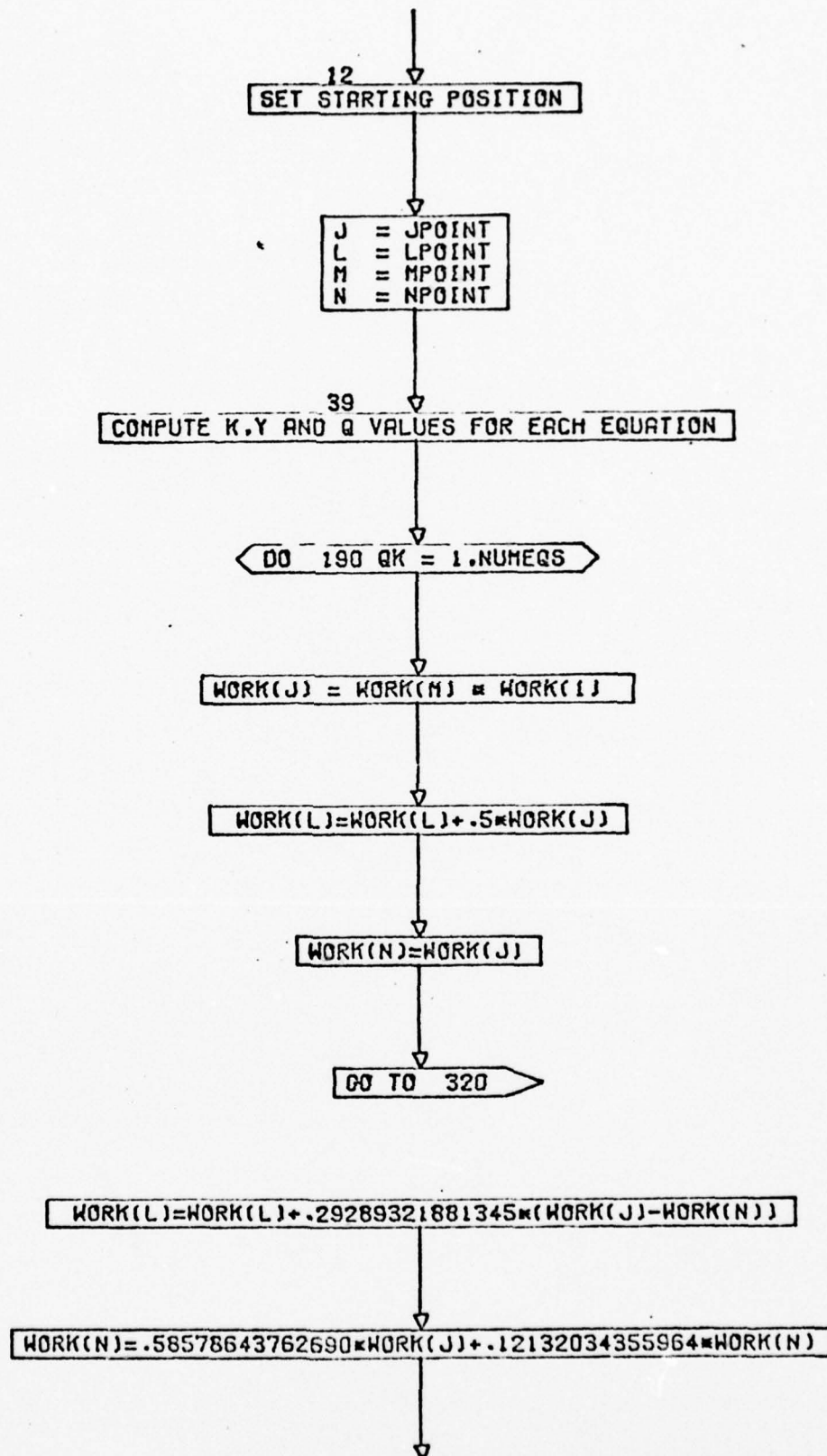
↓  
DO 101 I=1,3

↓  
CONT. ON PG 6









↓  
GO TO 320

WORK(L)=WORK(L)+1.7071067811865\*(WORK(J)-WORK(N))

WORK(N)=3.4142135623731\*WORK(J)-4.1213203435596\*WORK(N)

GO TO 320

WORK(L)=WORK(L)+.16666666666667\*WORK(J)-.33333333333333\*

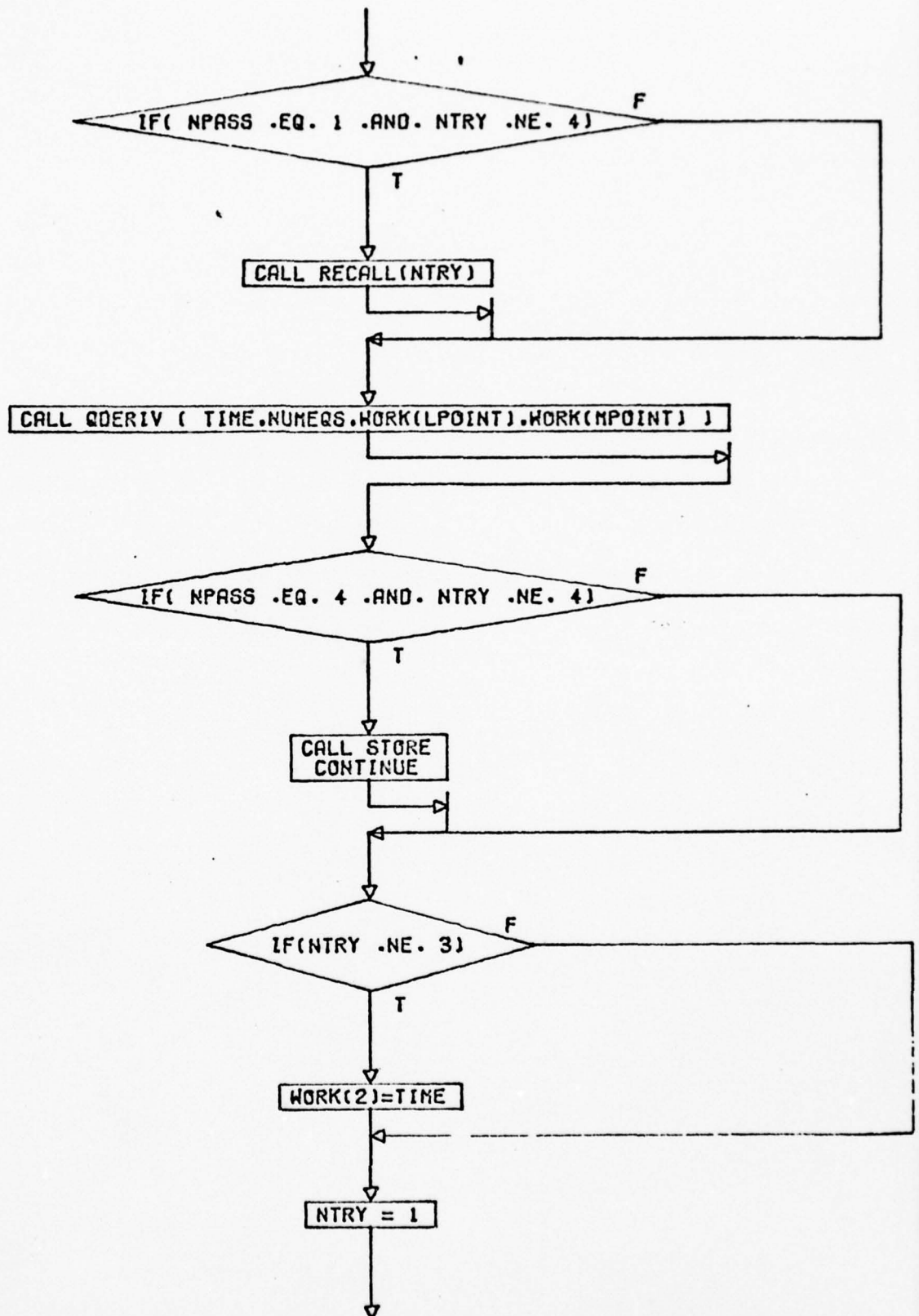
1 CONTINUE WORK(N)

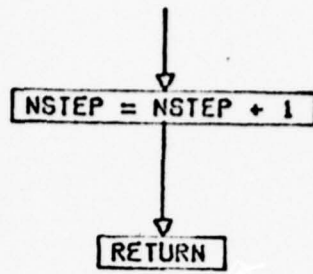
12 INCREMENT POINTERS

J = J + 1  
L = L + 1  
M = M + 1

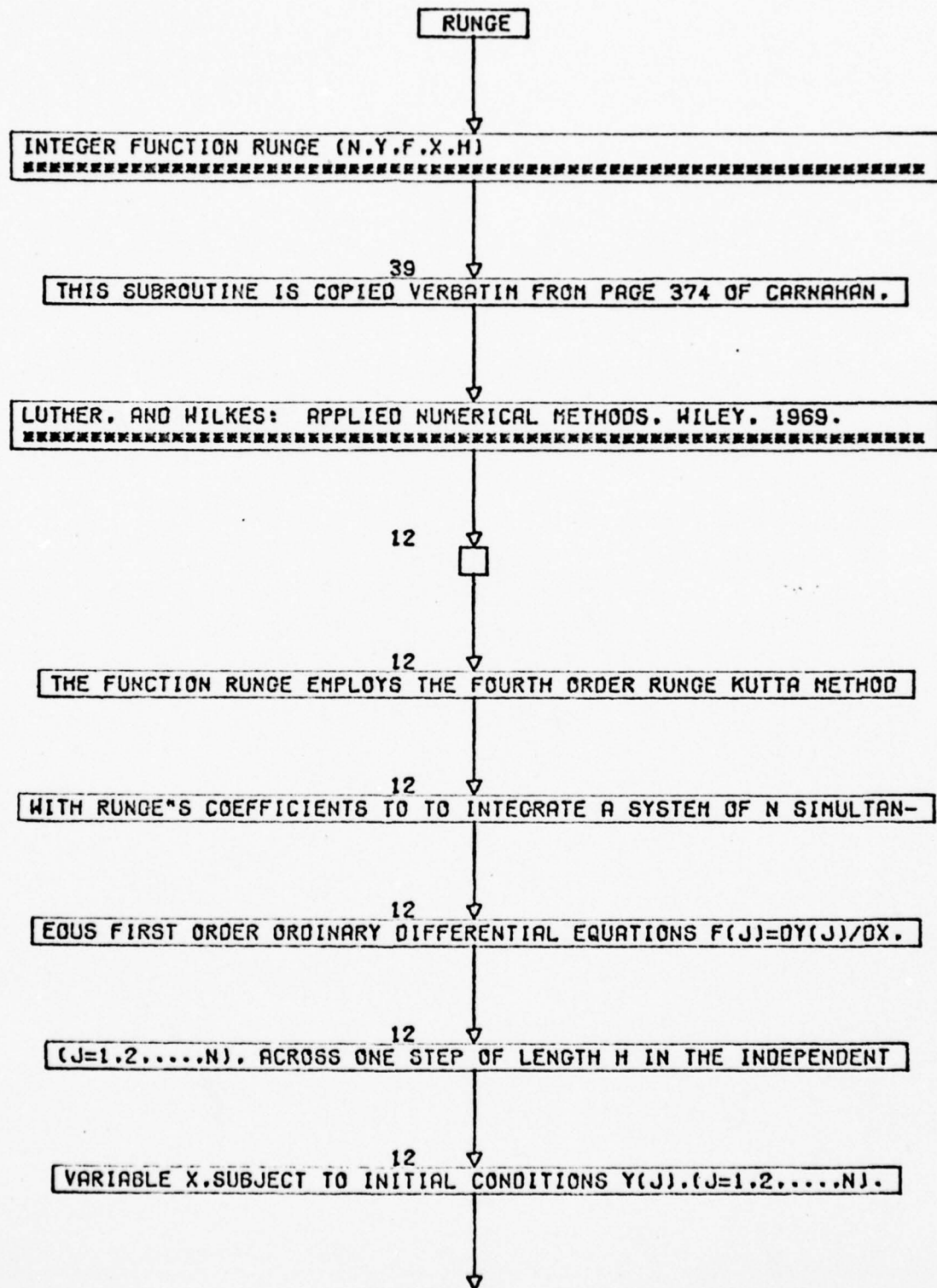
N = N + 1  
CONTINUE

TIME = QSAVE + WORK(1) \* QA(NPASS)



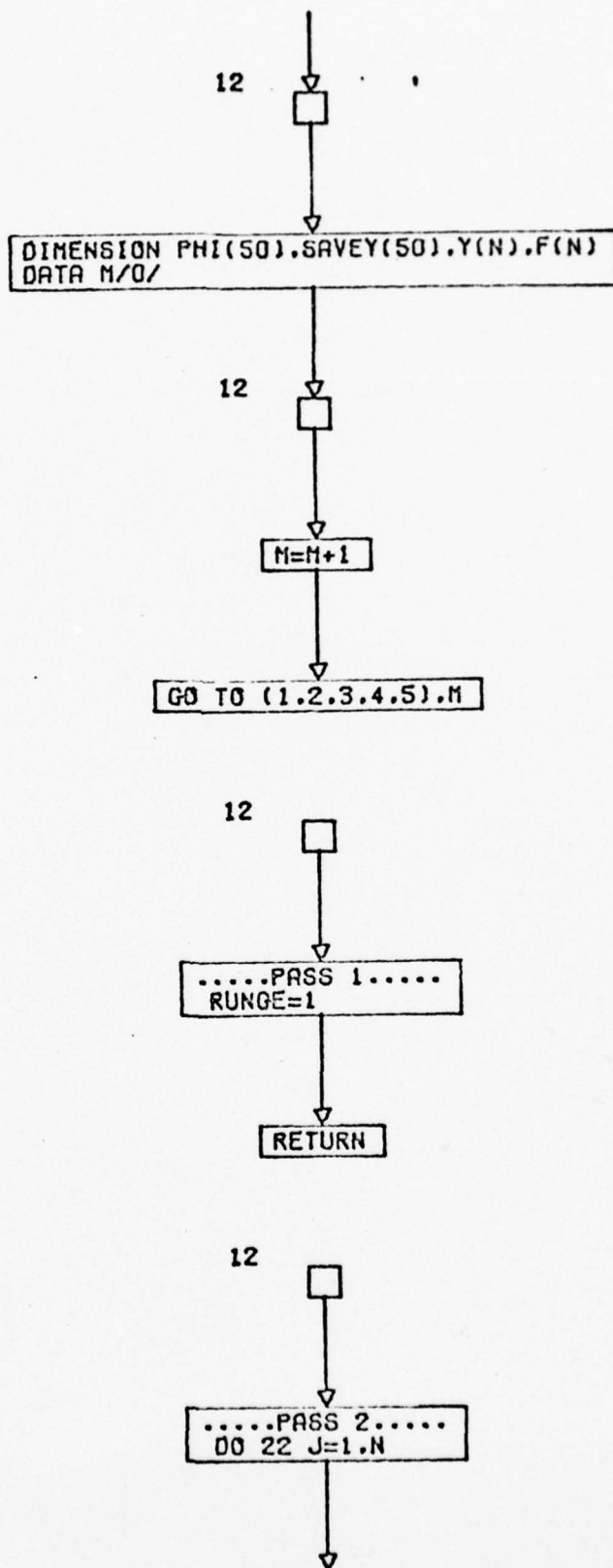


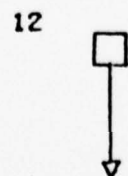
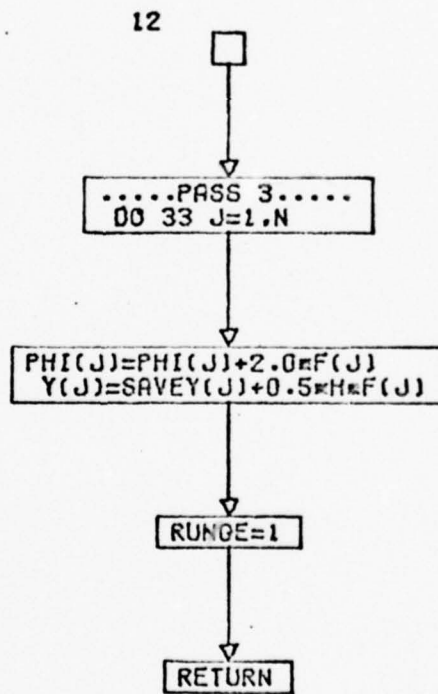
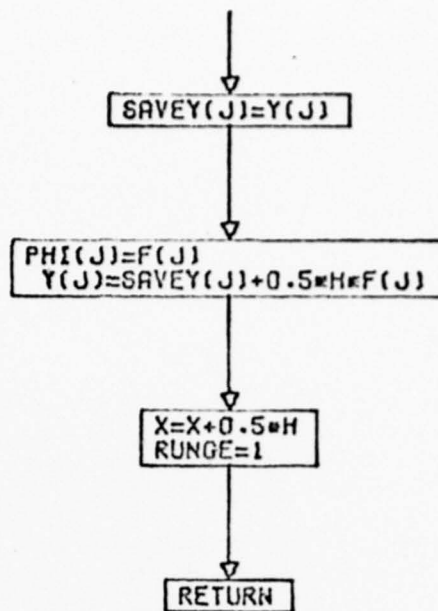
END











.....PASS 4.....  
DO 44 J=1,N

$\text{PHI}(J) = \text{PHI}(J) + 2.0 \times F(J)$   
 $Y(J) = \text{SAVEY}(J) + H \times F(J)$

$X = X + 0.5 \times H$   
RUNGE=1

RETURN

12

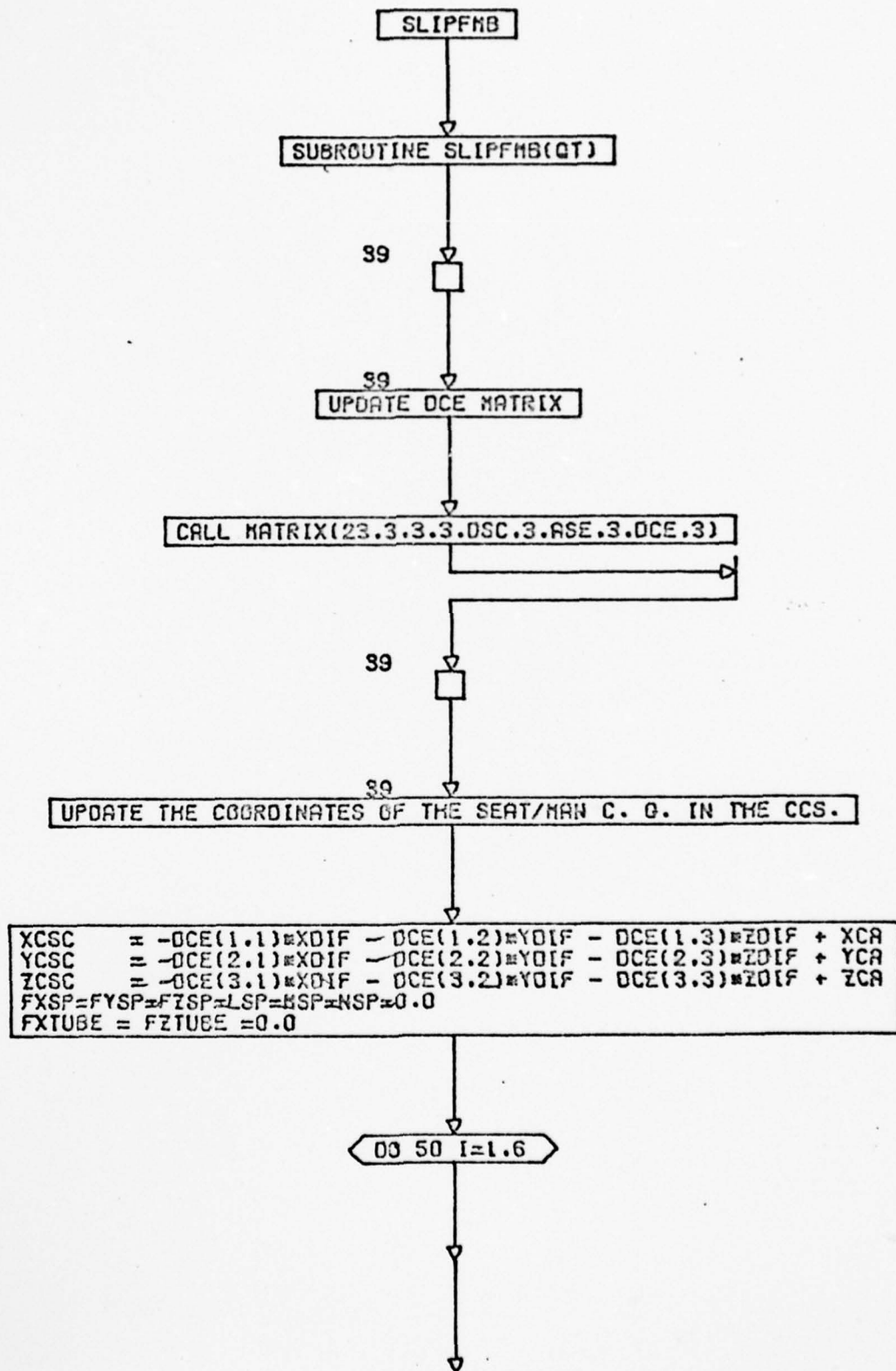
.....PASS 5.....  
DO 55 J=1,N  
 $Y(J) = \text{SAVEY}(J) + (\text{PHI}(J) + F(J)) \times H / 6.0$

M=0  
RUNGE=0

RETURN

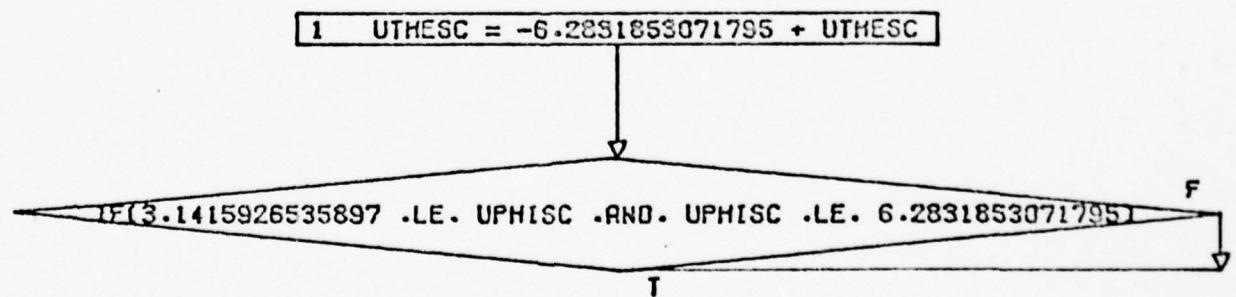
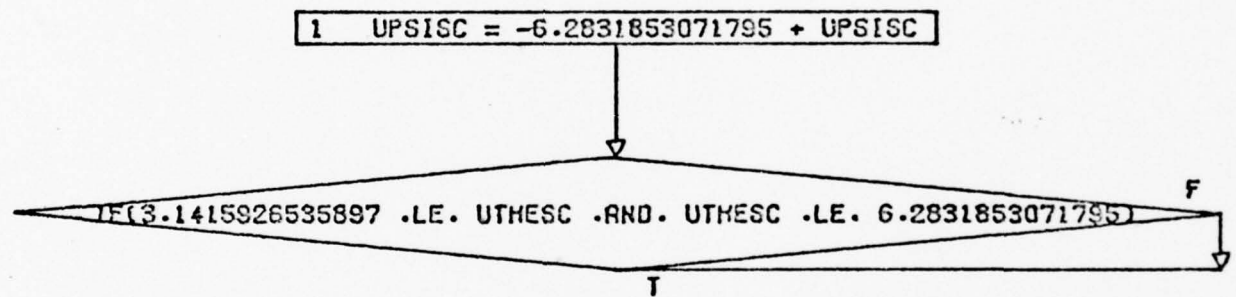
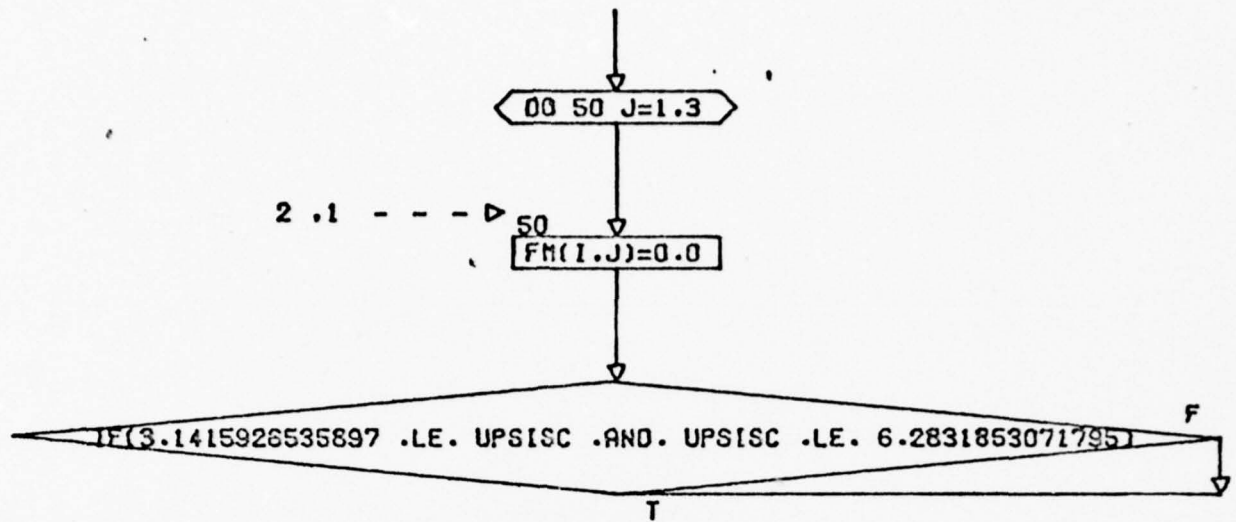
12

END



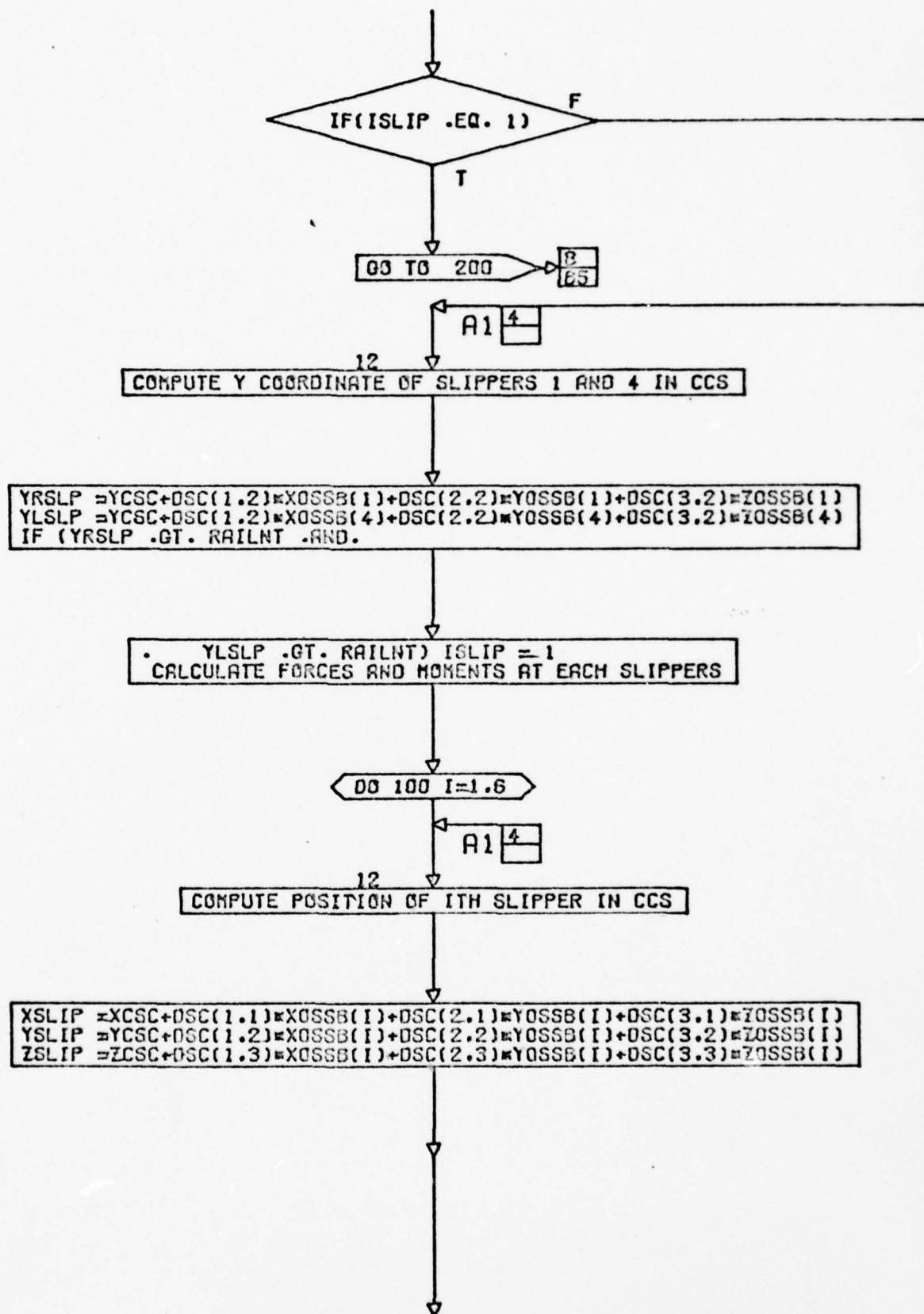
CONT. ON PG 2



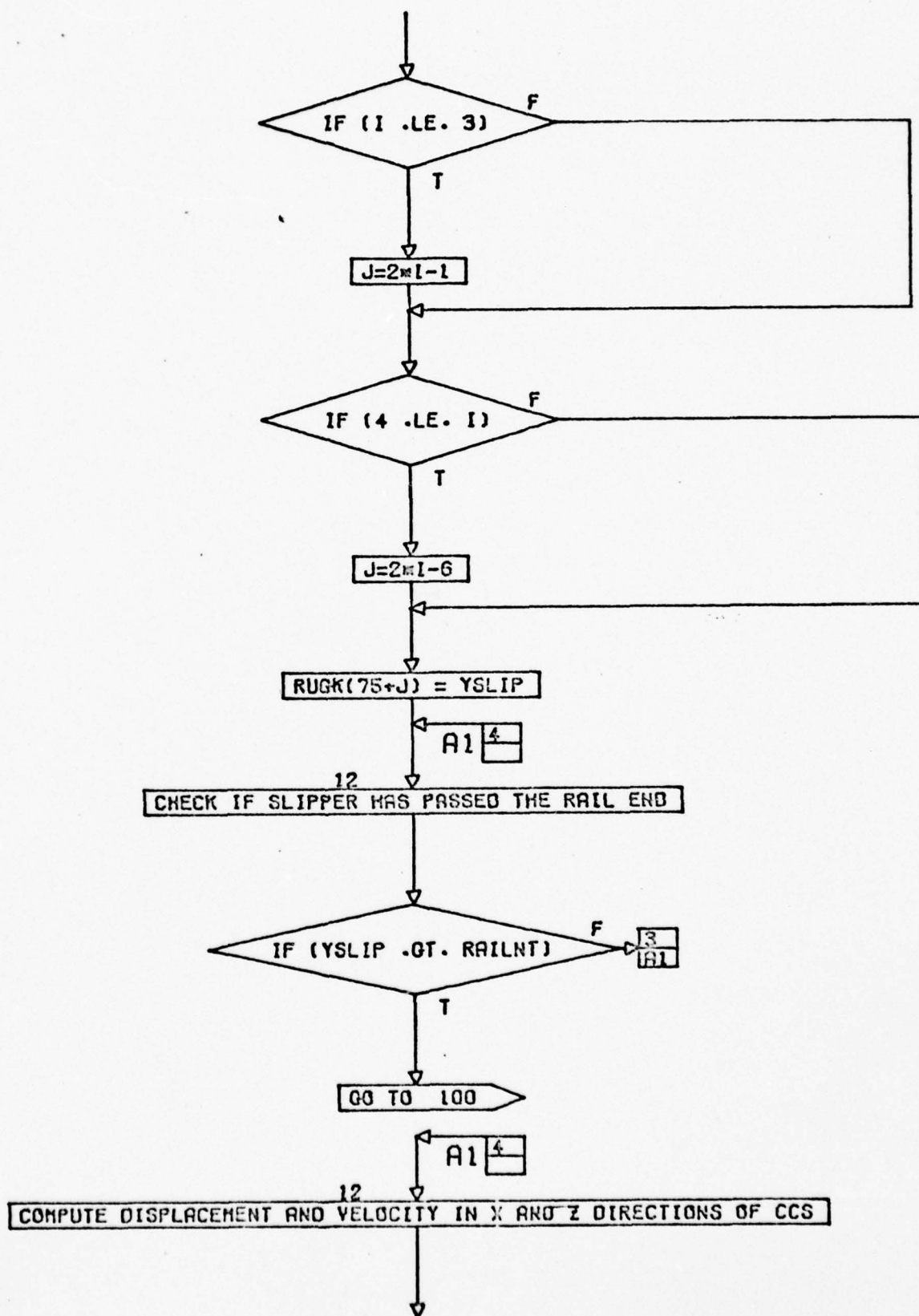


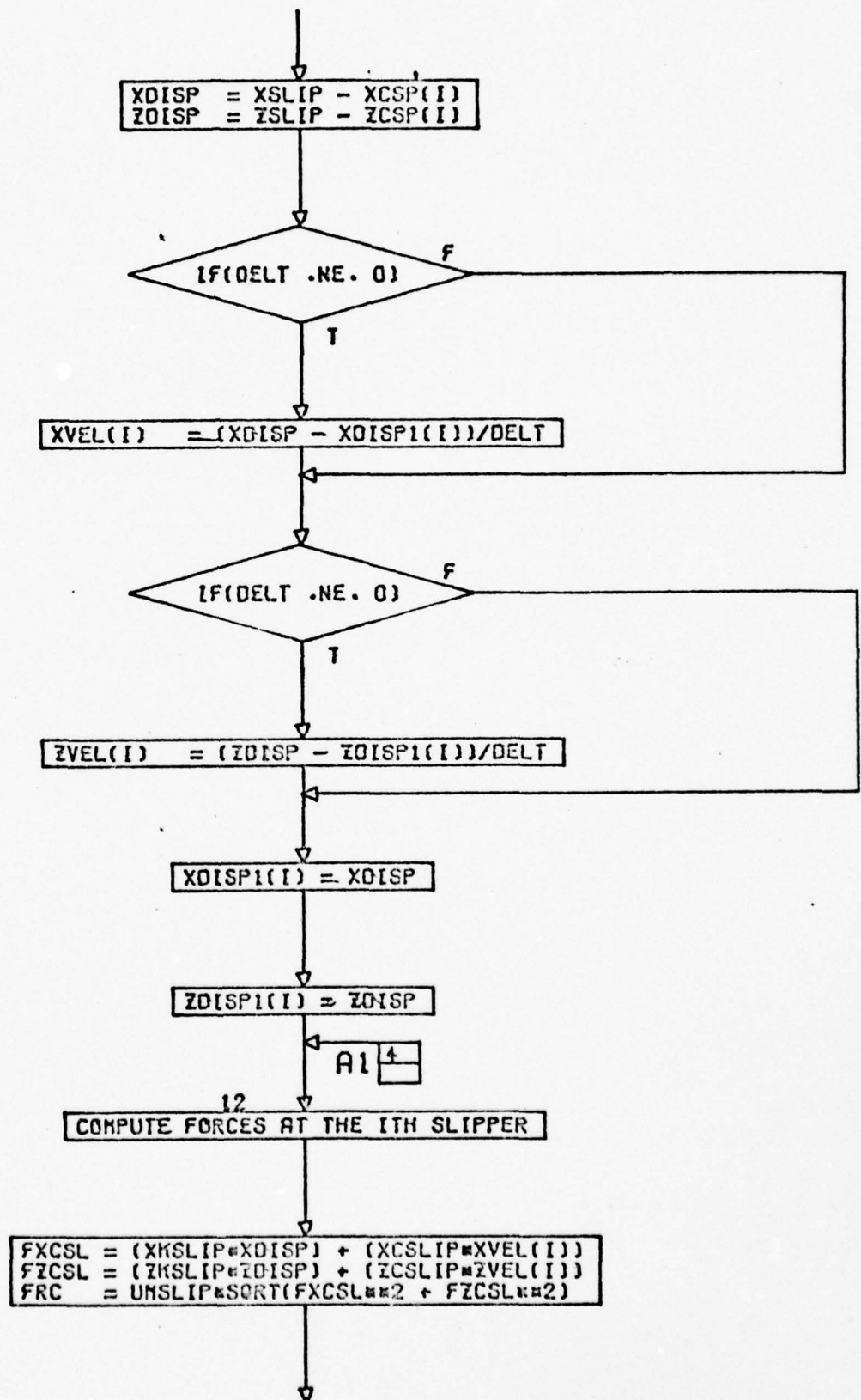
1 UPHISC = -6.2831853071795 + UPHISC

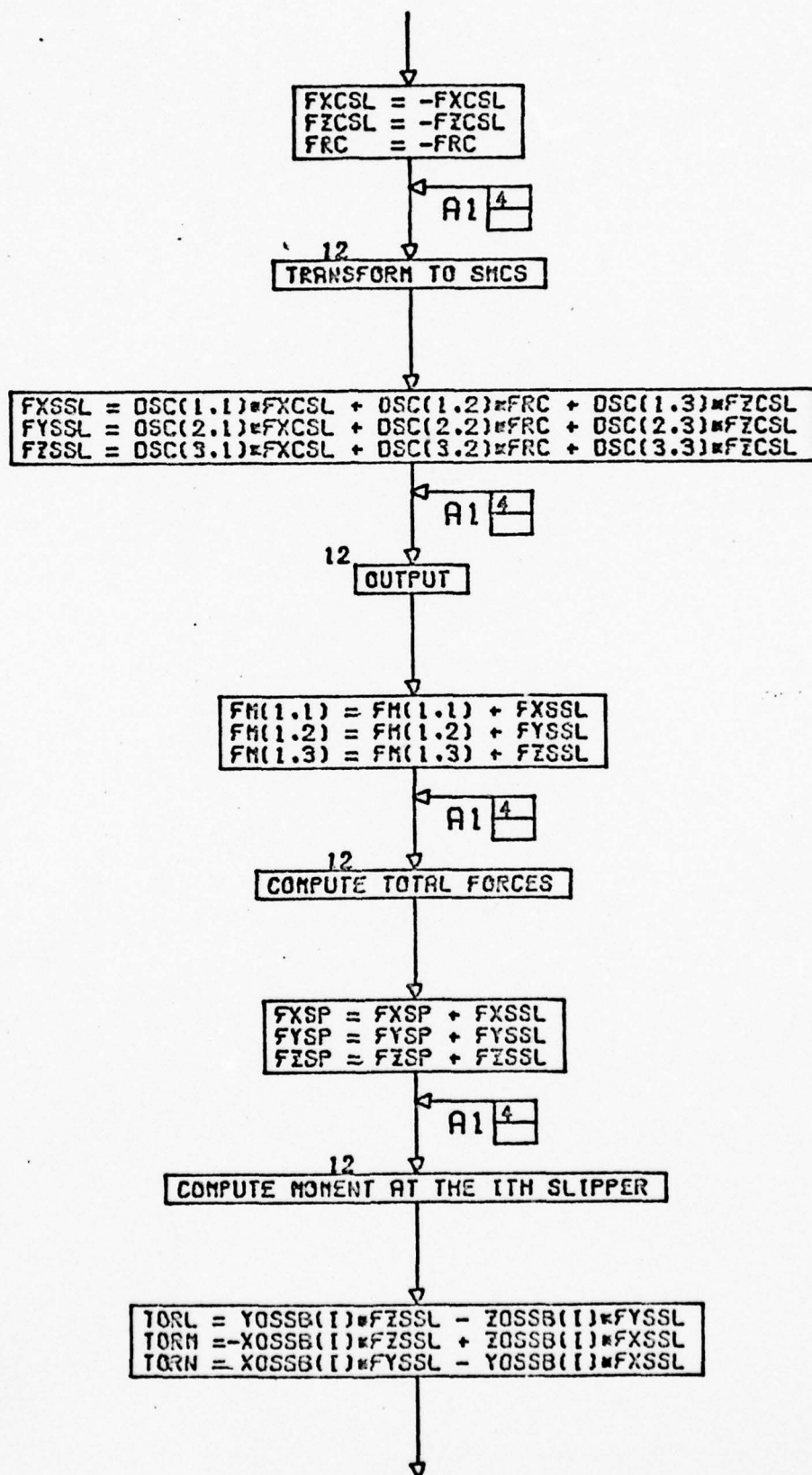
CONT. ON PG 3



CONT. ON PG 4

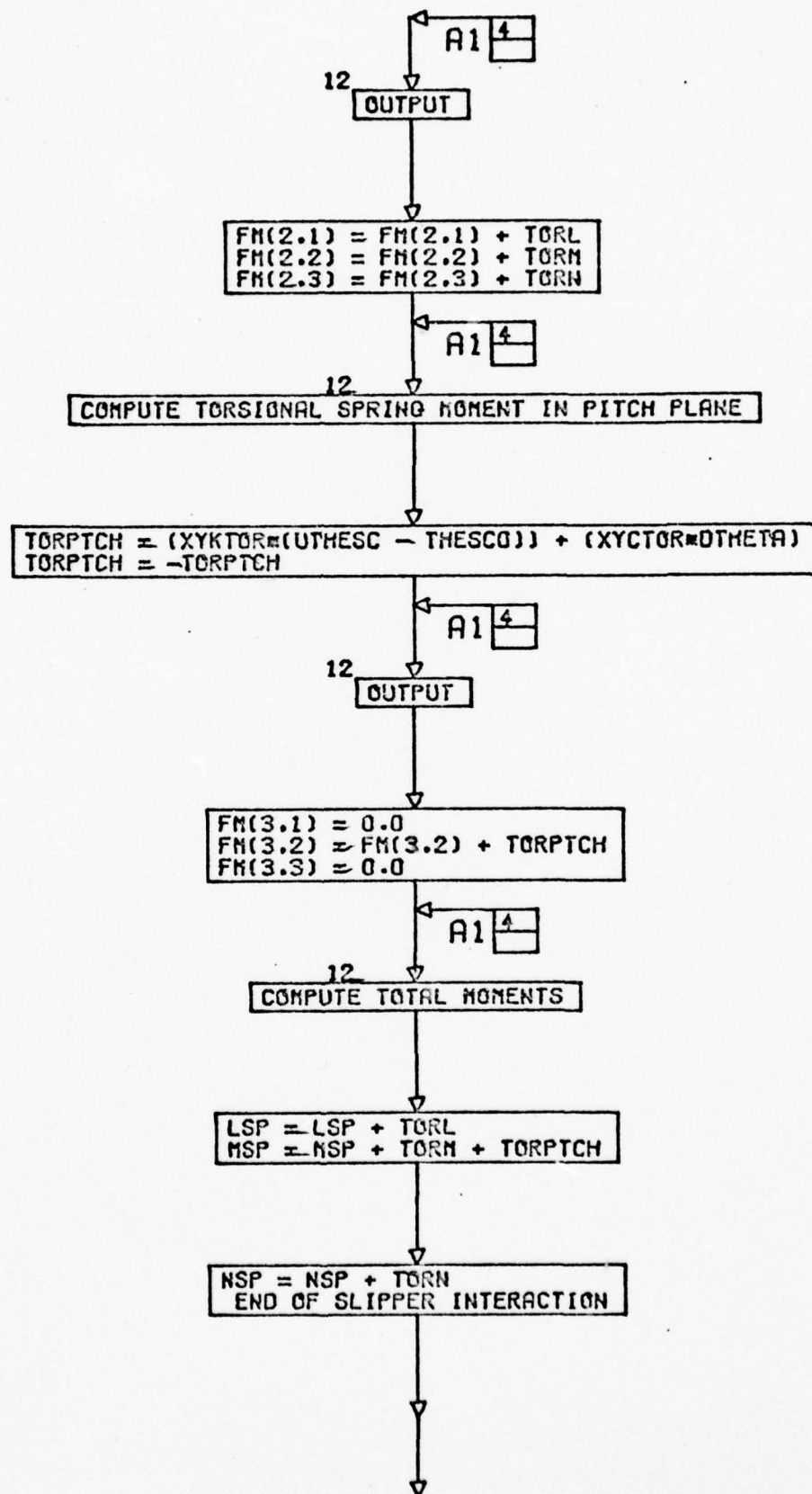




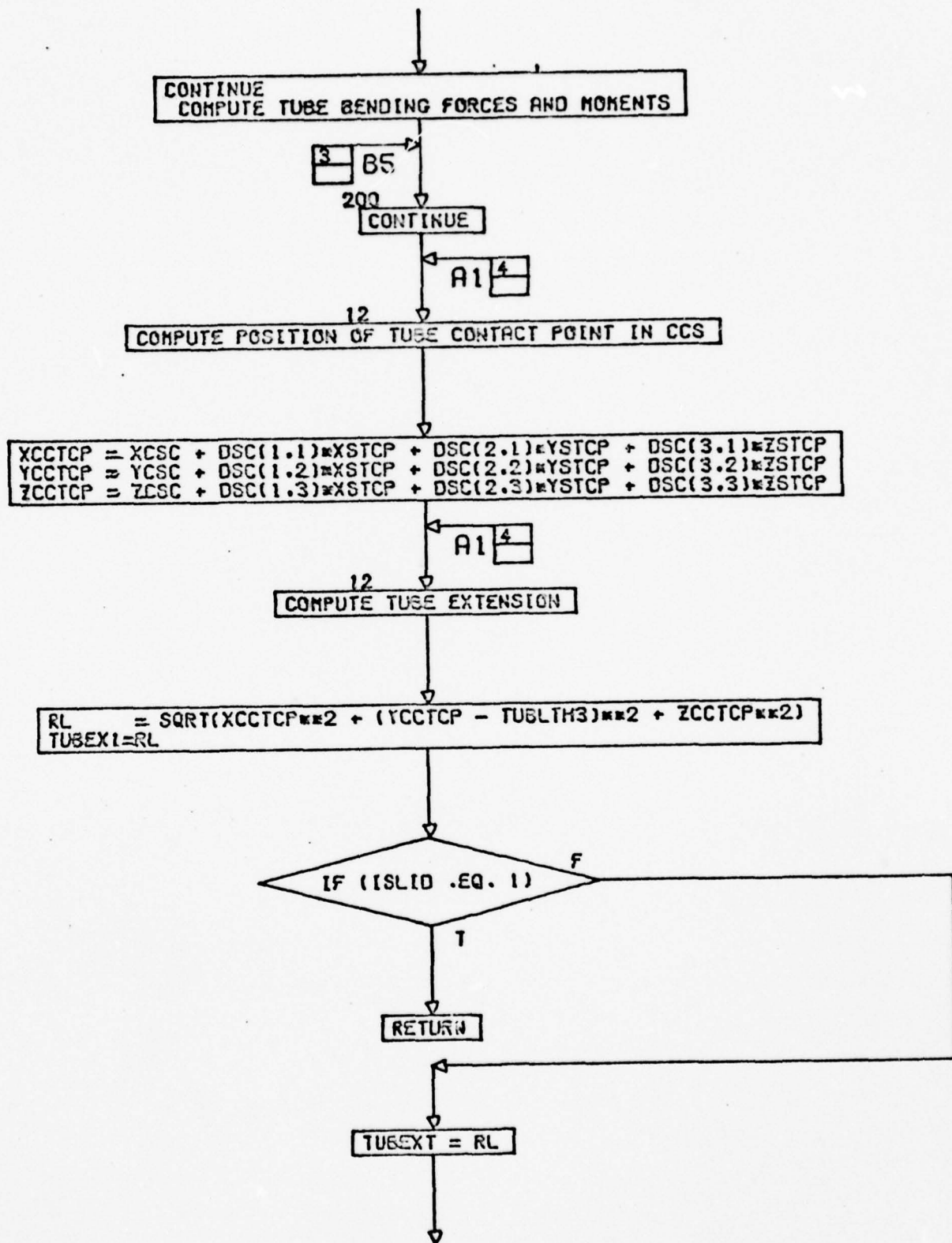


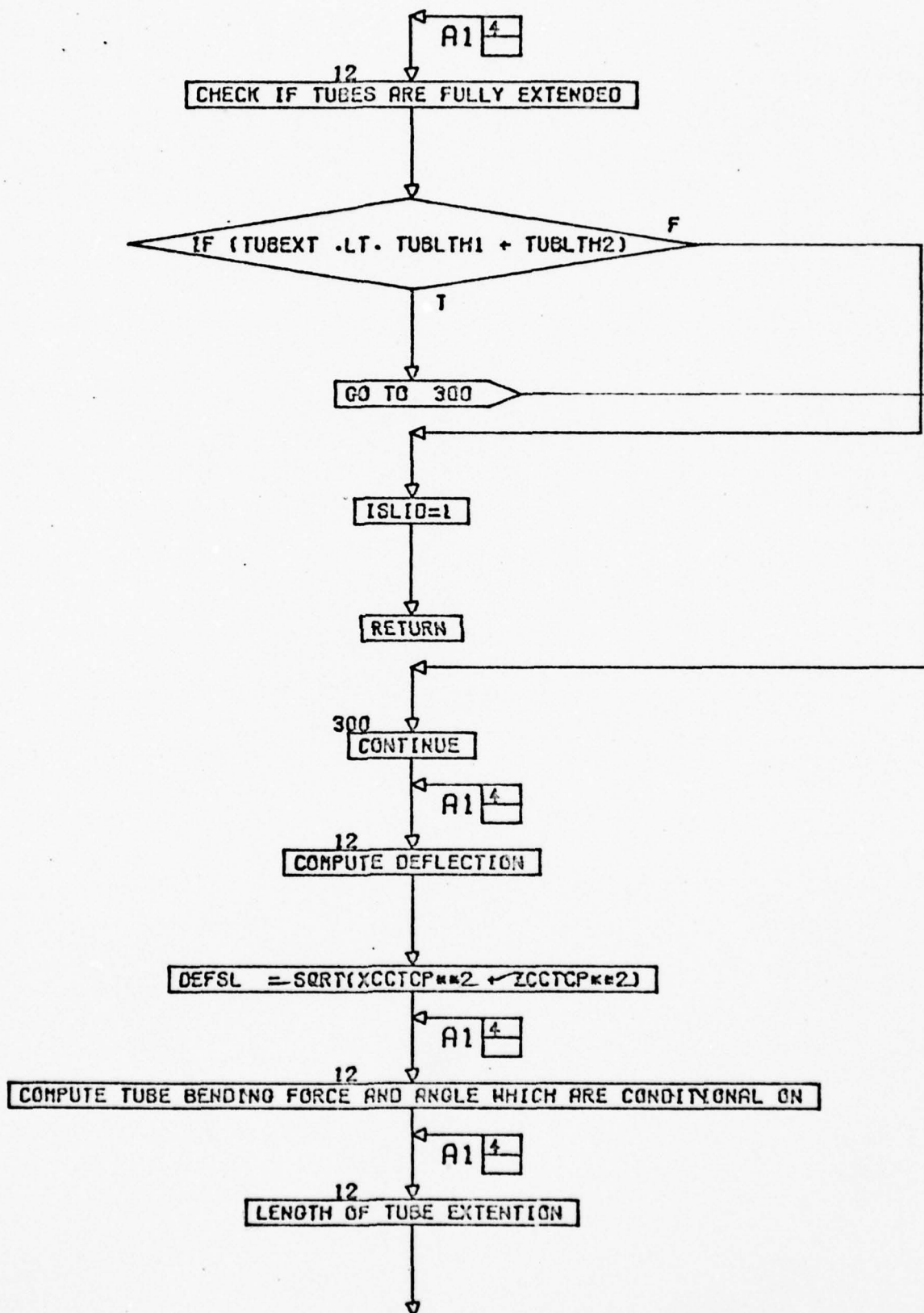
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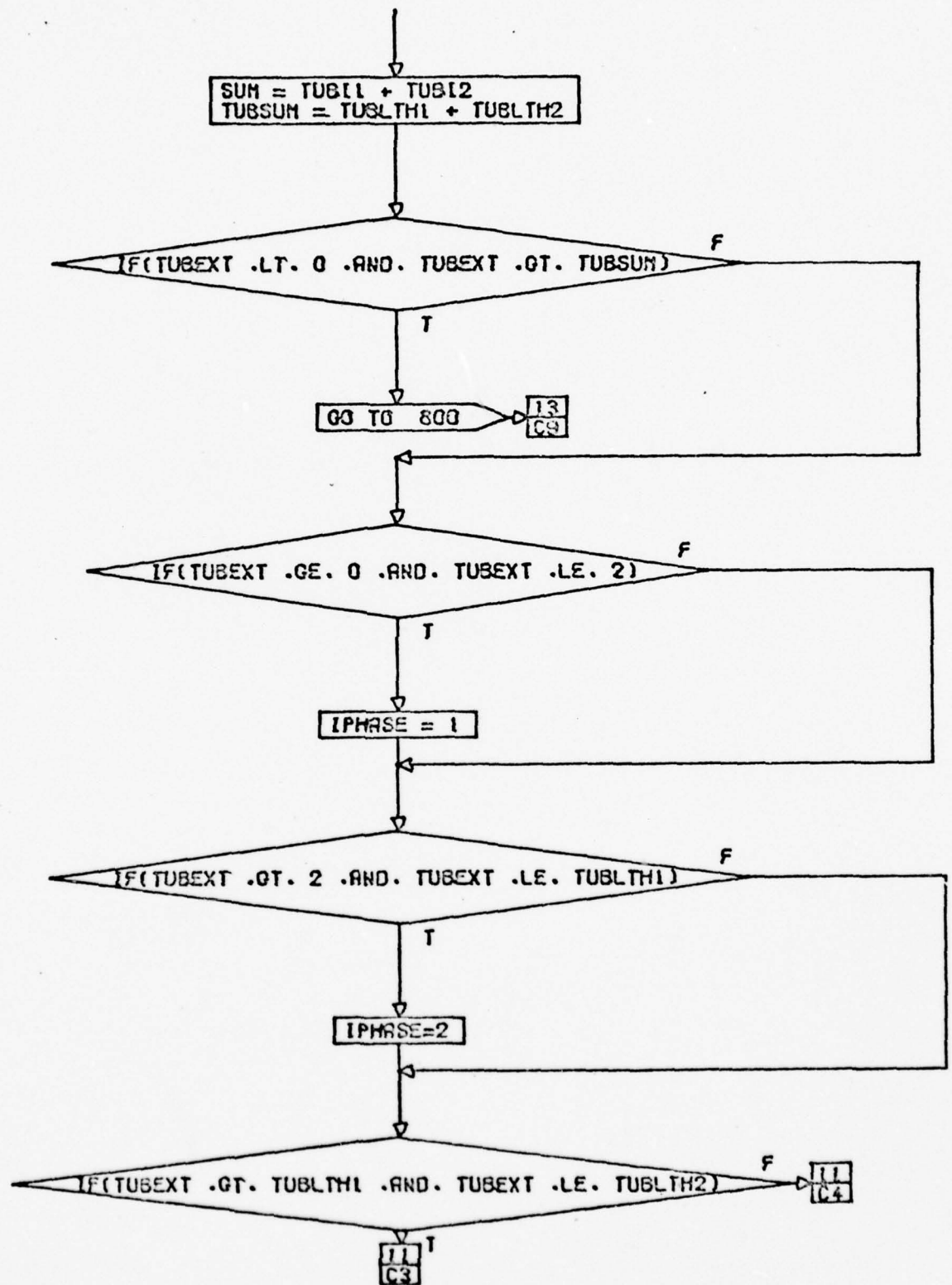


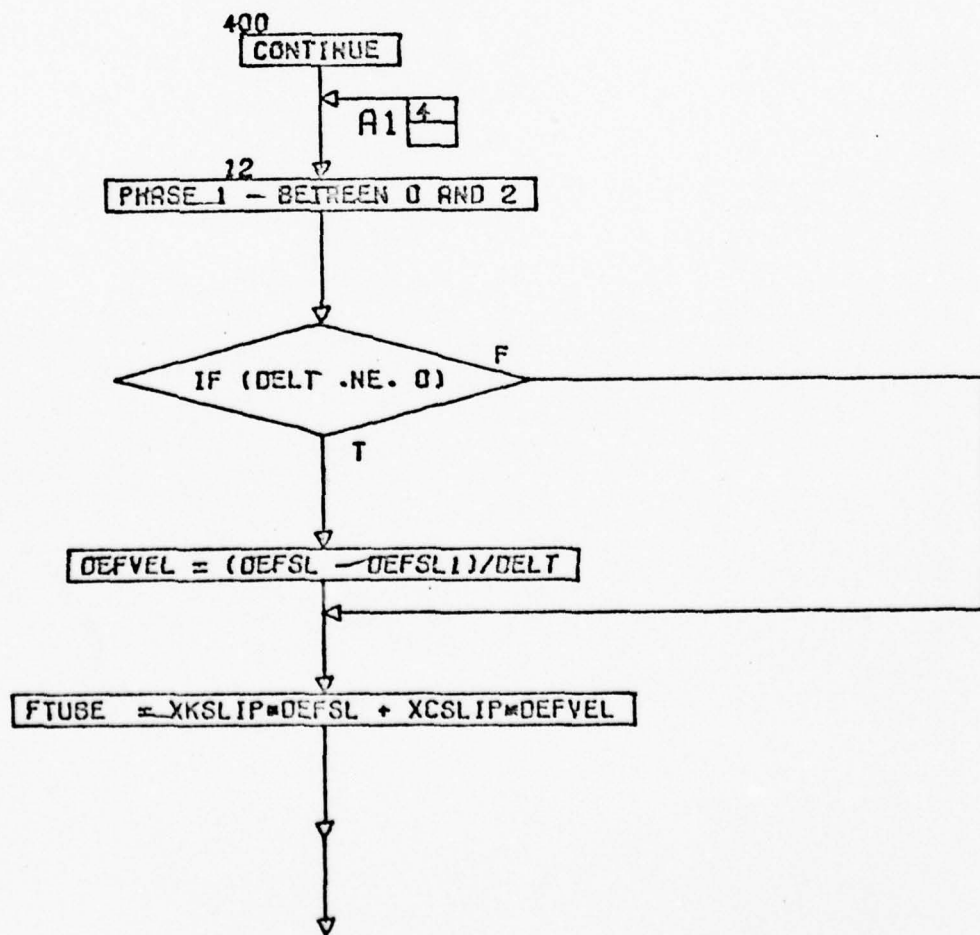
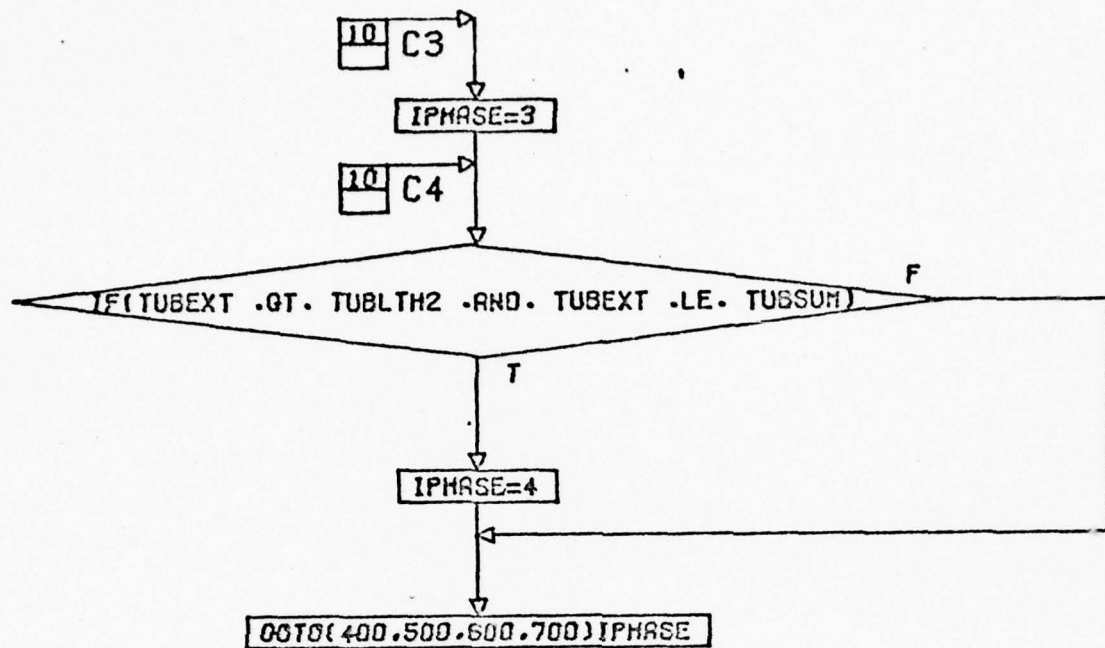


CONT. ON PG 8









CONT. ON PG 12



↓

$DEFSL1 = DEFSL$ $THETAB = (FTUBE * (TUBEXT * 2)) / (2 * ELMOD * SUM)$
---

GO TO 800 → 

13
C9

500  
CONTINUE

← 

A1
4

12  
↓  
PHASE 2 — BETWEEN 2 AND TUBLTH1

↓

$FTUBE = (3 * DEFSL * ELMOD * SUM) / (TUBEXT * 3)$ $THETAB = (FTUBE * (TUBEXT * 2)) / (2 * ELMOD * SUM)$
---

GO TO 800 → 

13
C9

600  
CONTINUE

← 

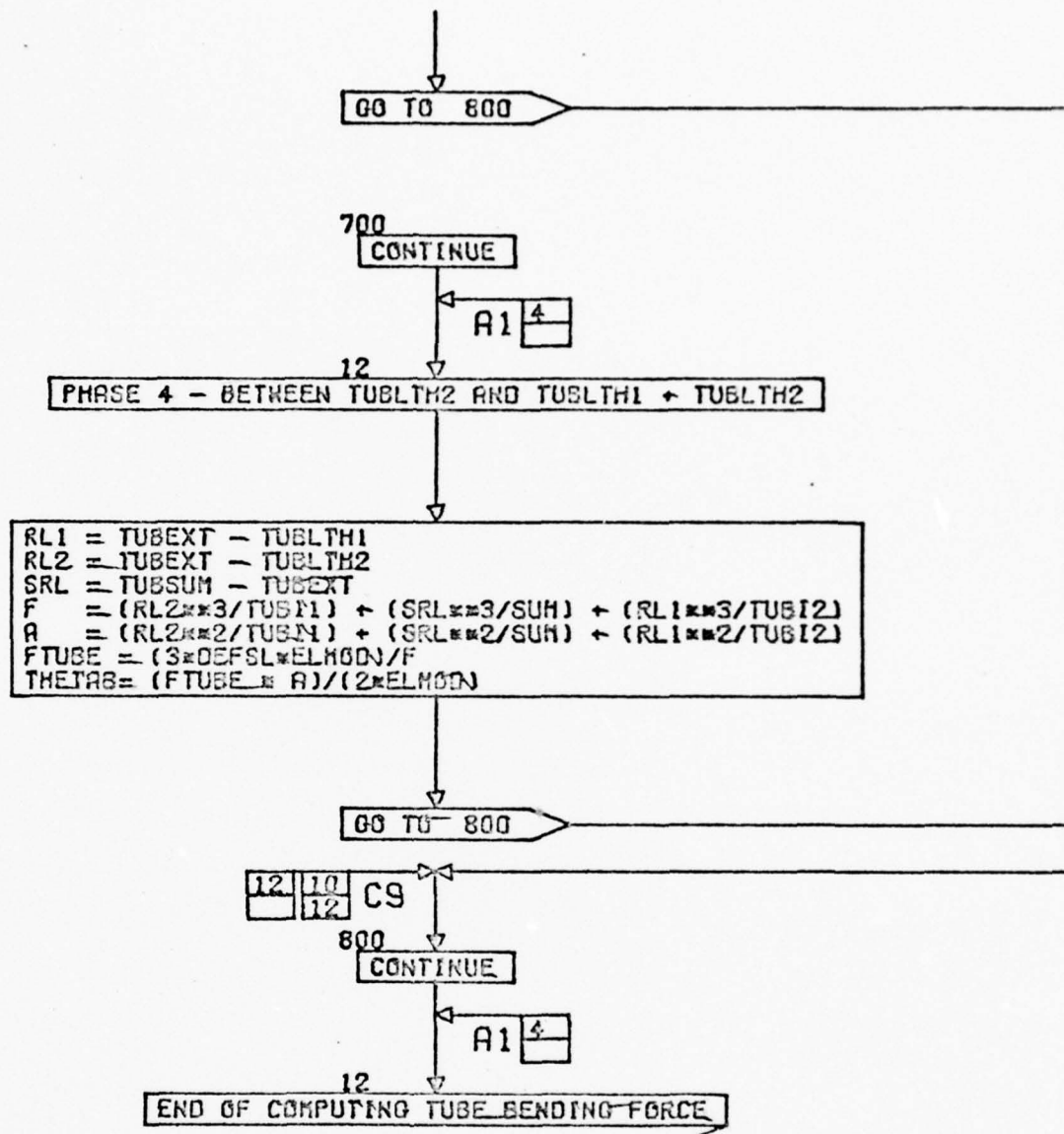
A1
4

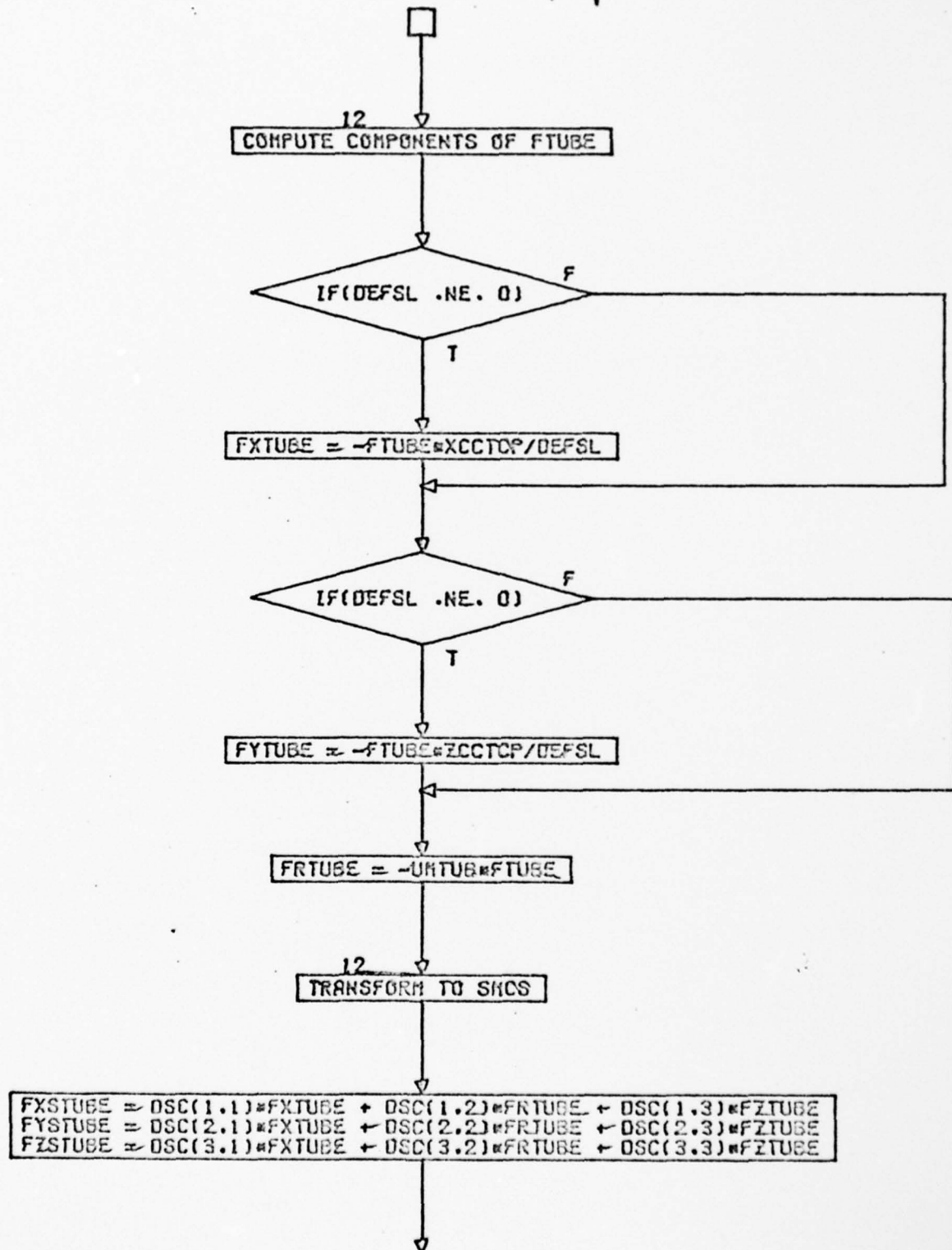
12  
↓  
PHASE 3 — BETWEEN TUBLTH1 AND TUBLTH2

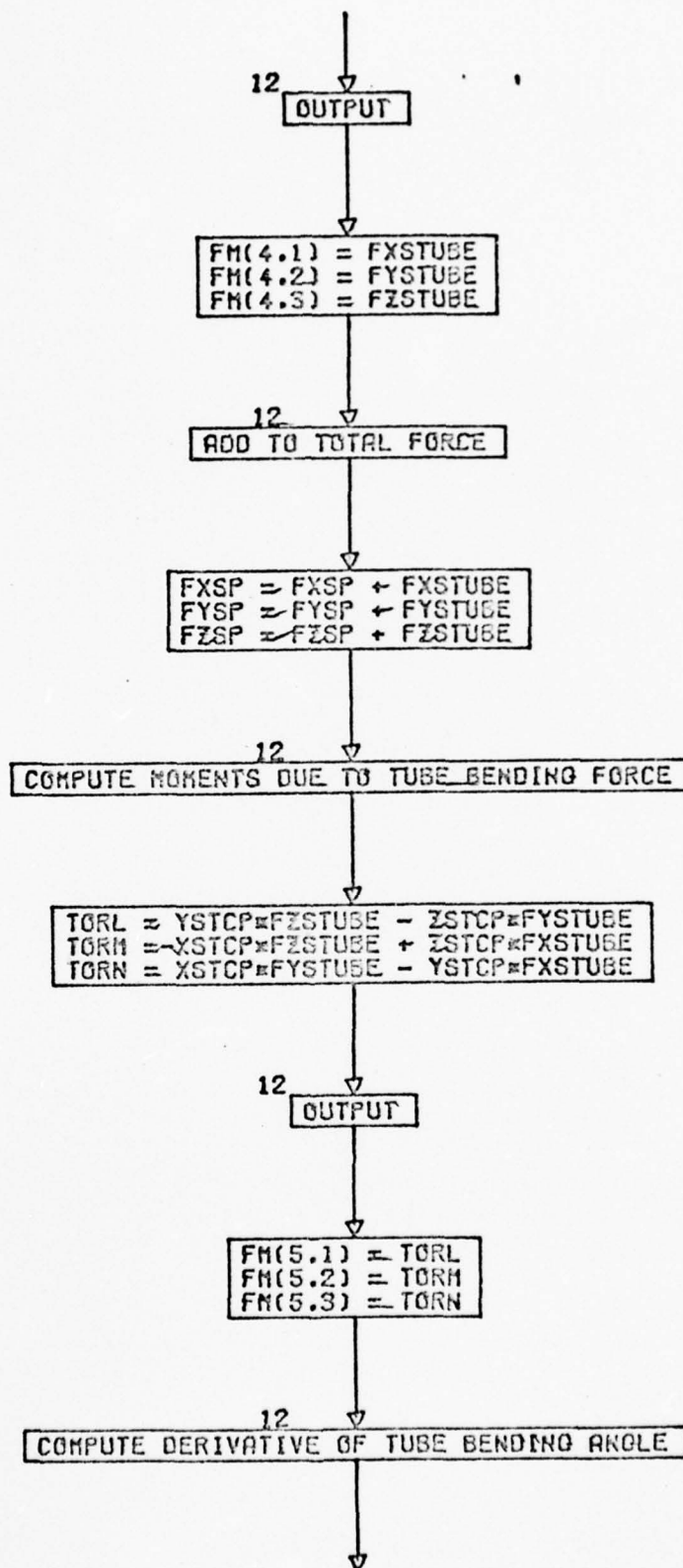
↓

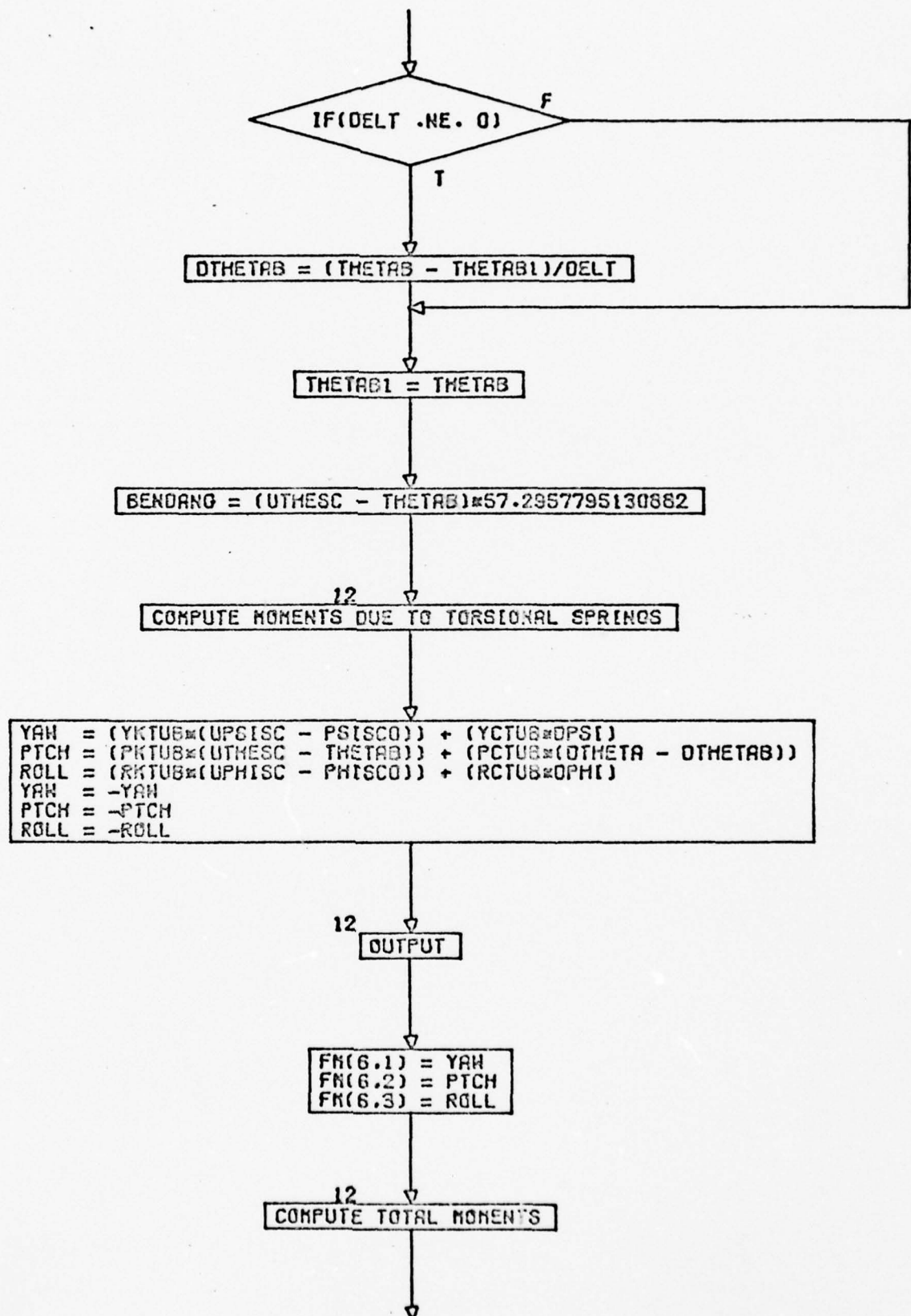
$F = (TUBEXT - TUBLTH1) * 3 / TUB11 + (TUBLTH1 * 3 / SUM)$ $A = (TUBEXT - TUBLTH1) * 2 / TUB11 + (TUBLTH1 * 2 / SUM)$ $FTUBE = (3 * DEFSL * ELMOD) / F$ $THETAB = (FTUBE * A) / (2 * ELMOD)$
---

↓  
CONT. ON PG 13

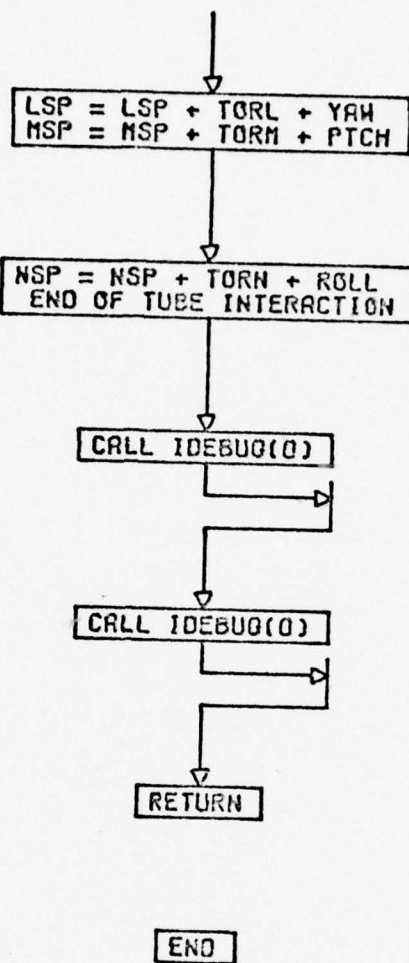


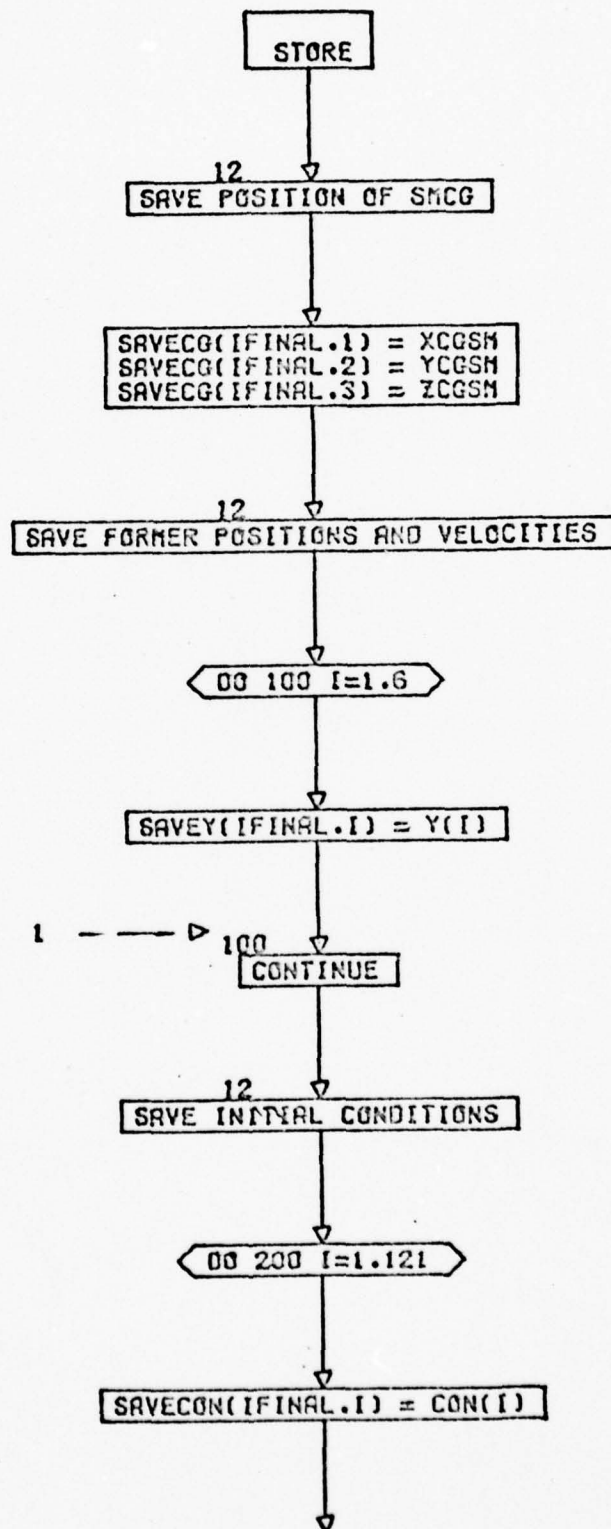


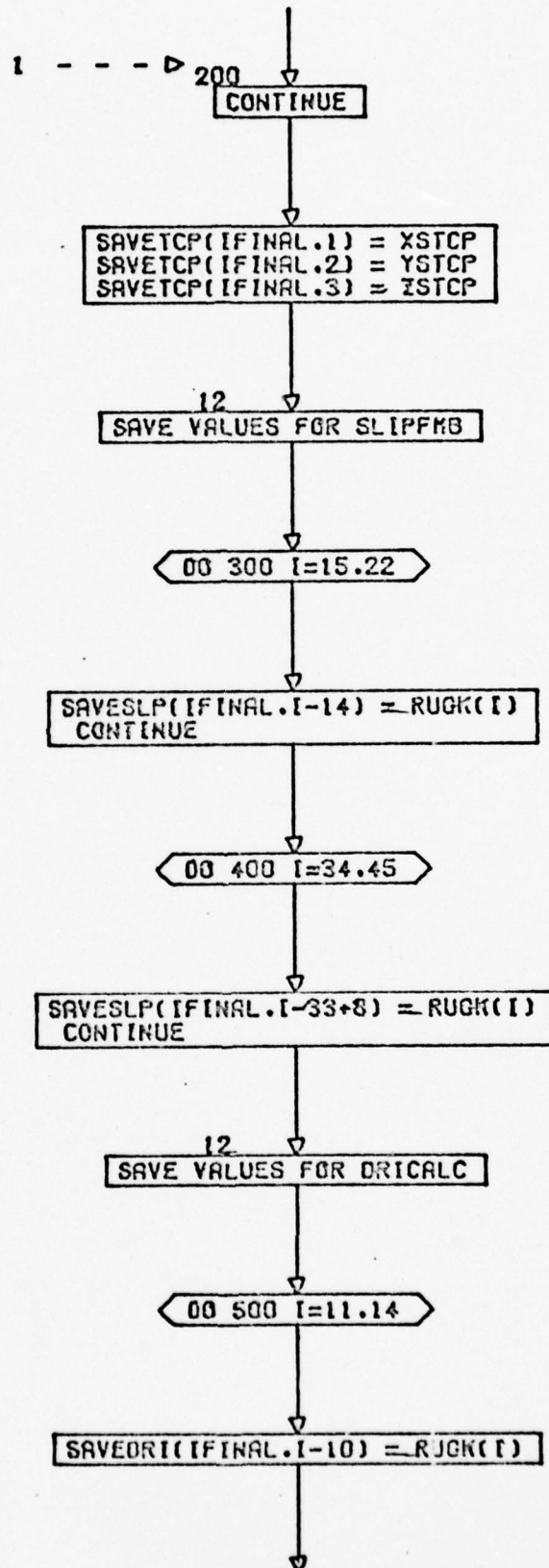


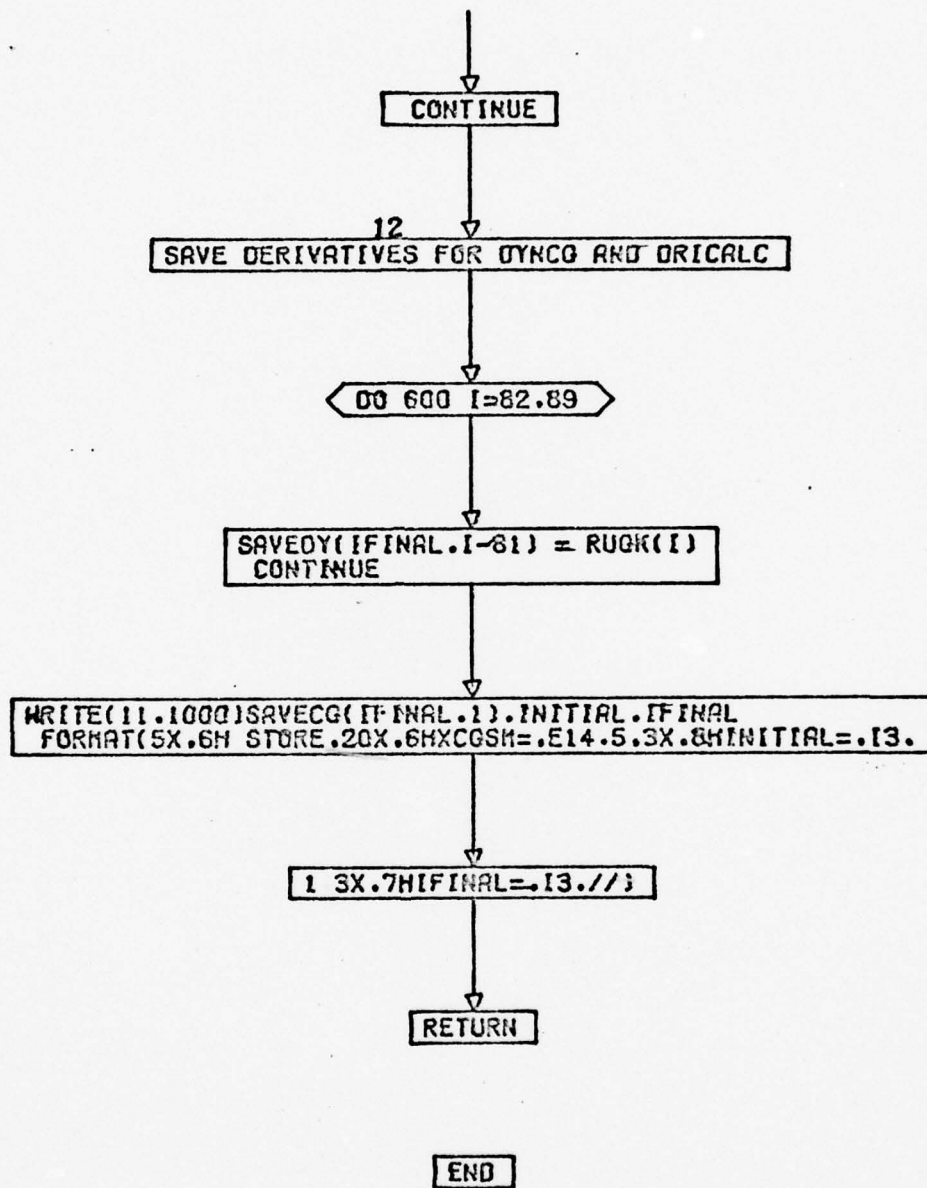


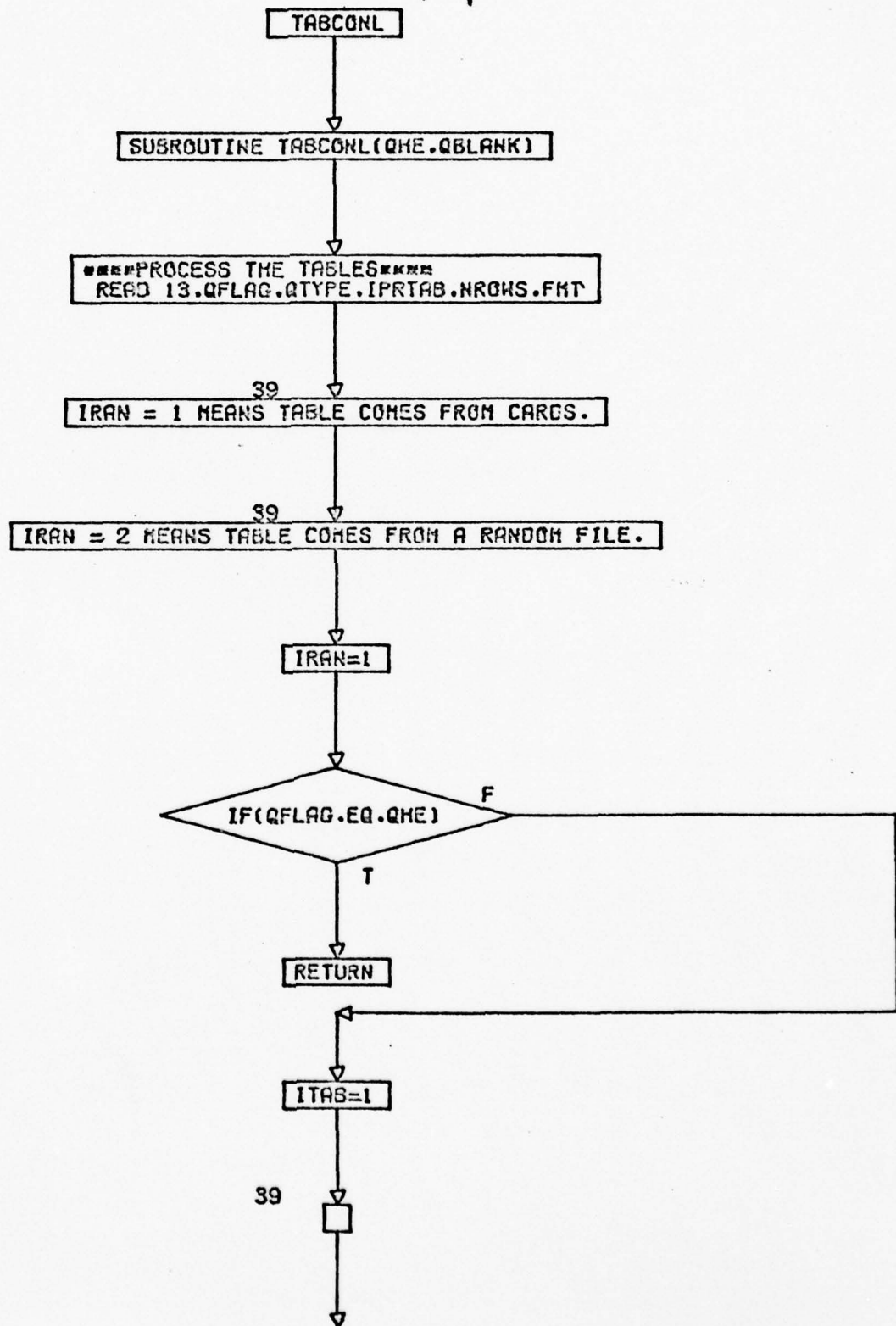




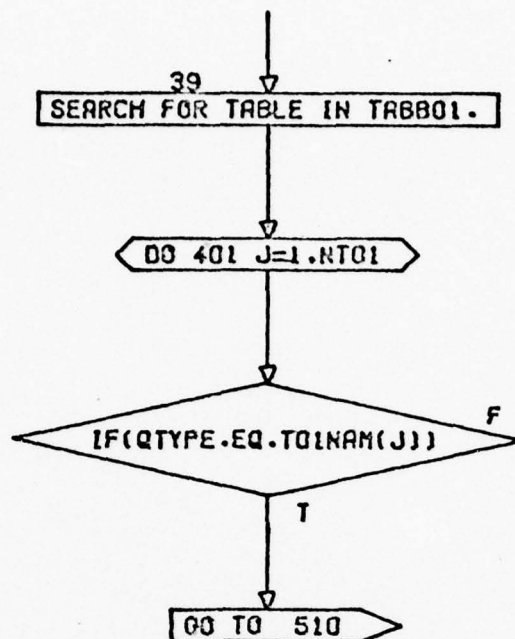




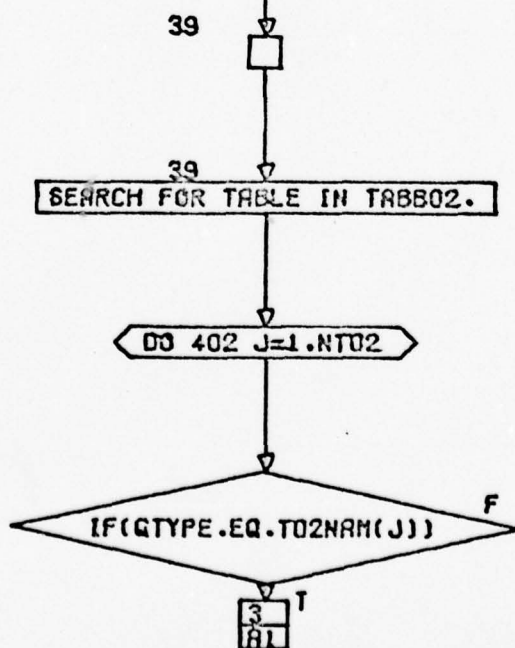


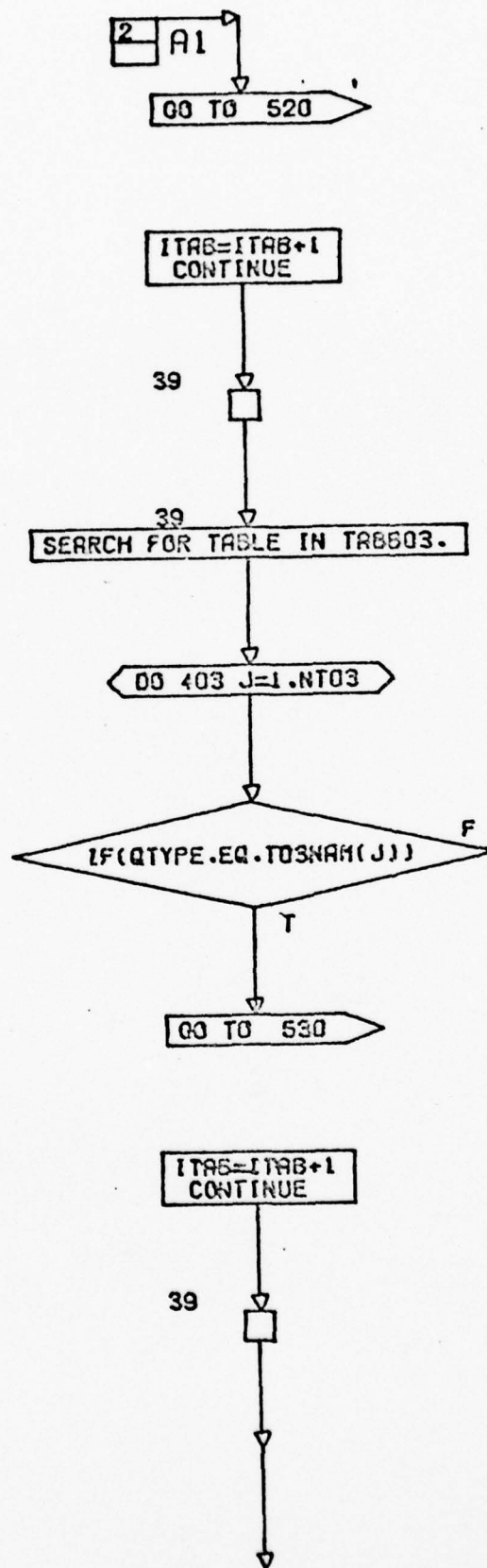




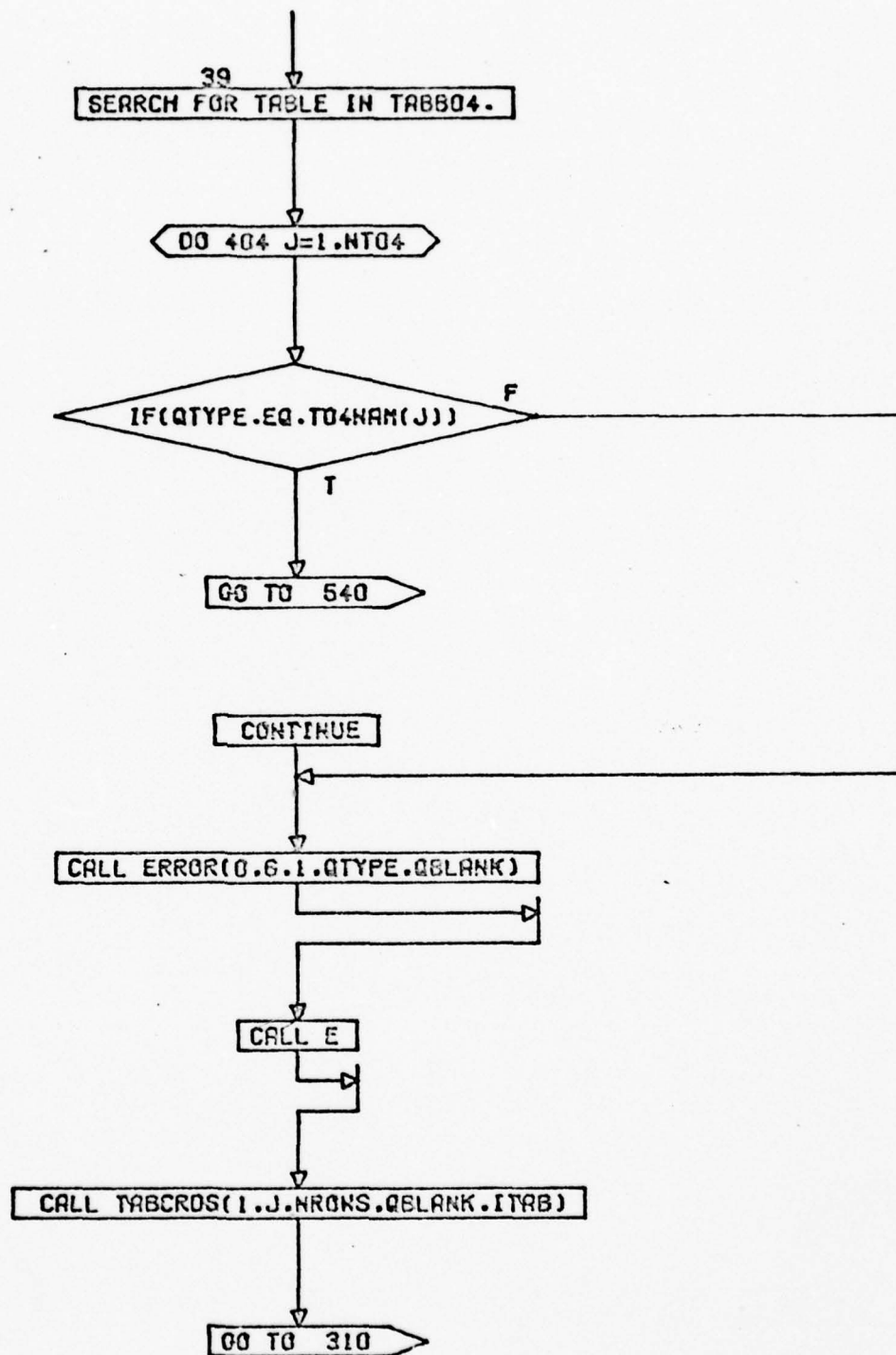


ITAB=ITAB+1  
CONTINUE





CONT. ON PG 4



CALL TABCROS(2,J,NROWS,QBLANK,ITAB)

GO TO 310

CALL TABCROS(3,J,NROWS,QBLANK,ITAB)

GO TO 310

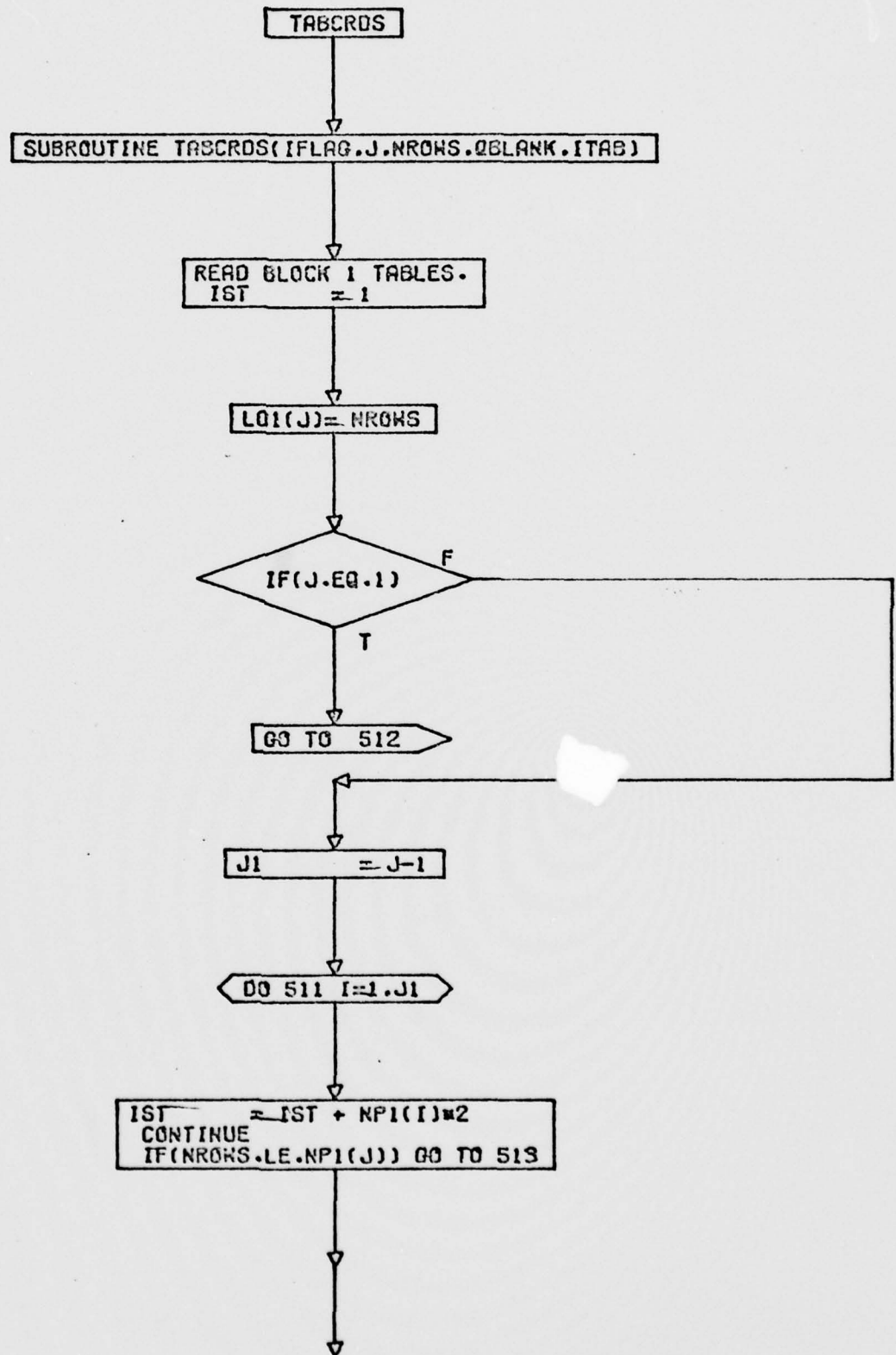
IF(IAROW.EQ.0) GO TO 541

QPCNT = QPCNT + 1

PRINT 222, QPCNT  
CALL ACT(J,NROWS)

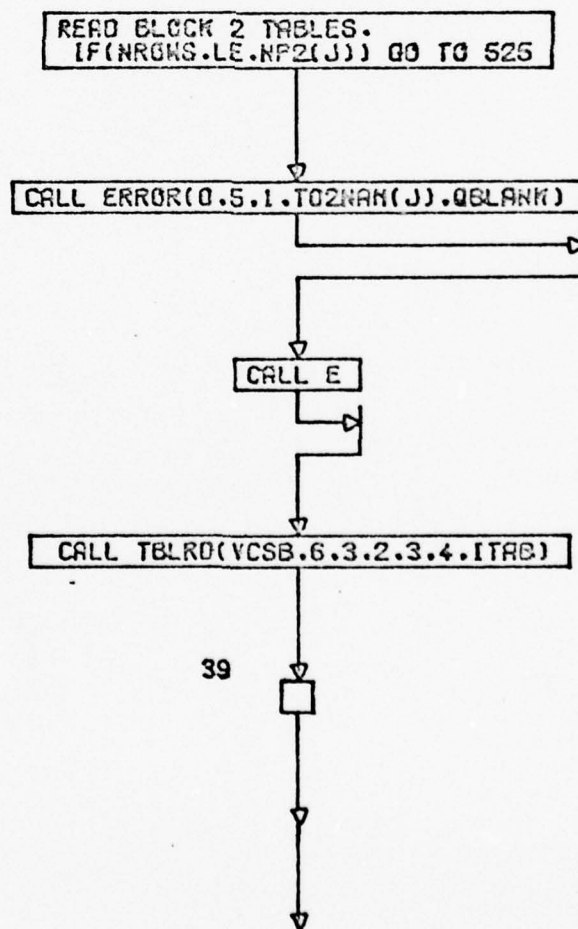
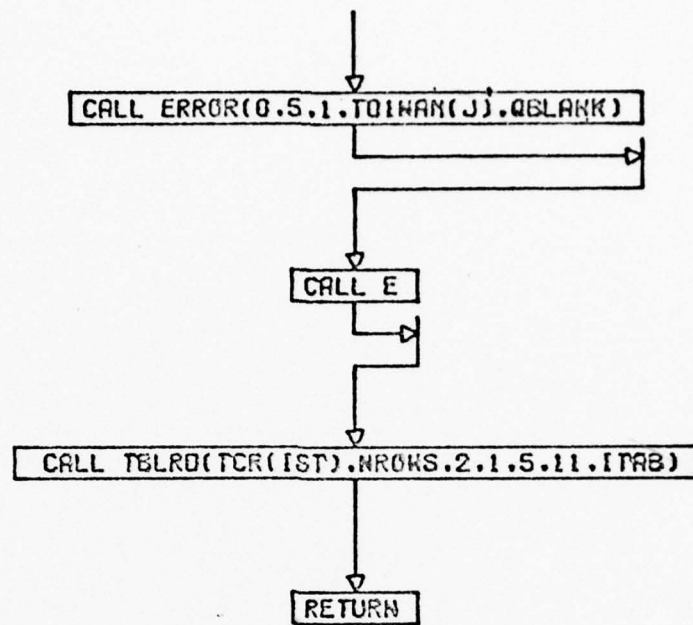
GO TO 310

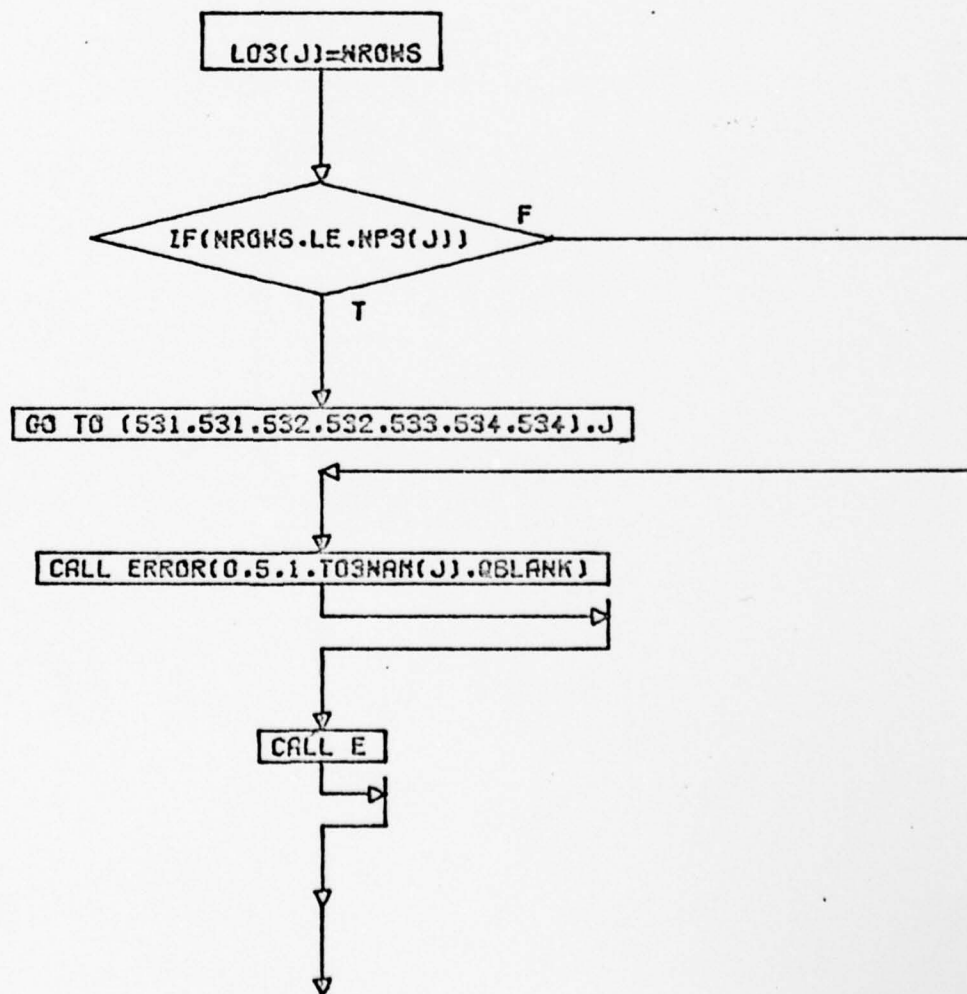
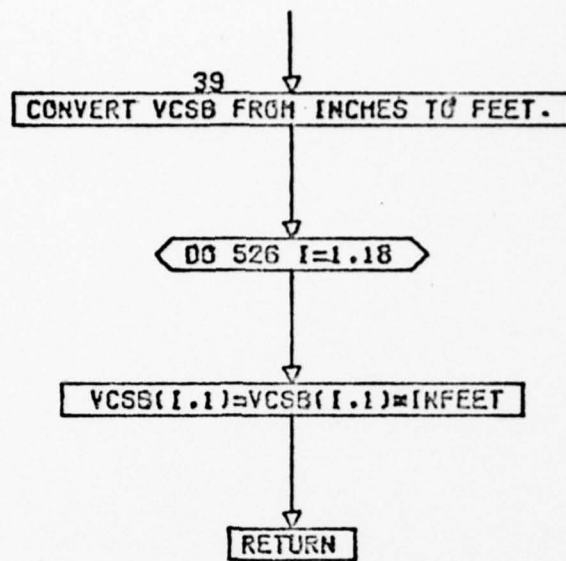
END



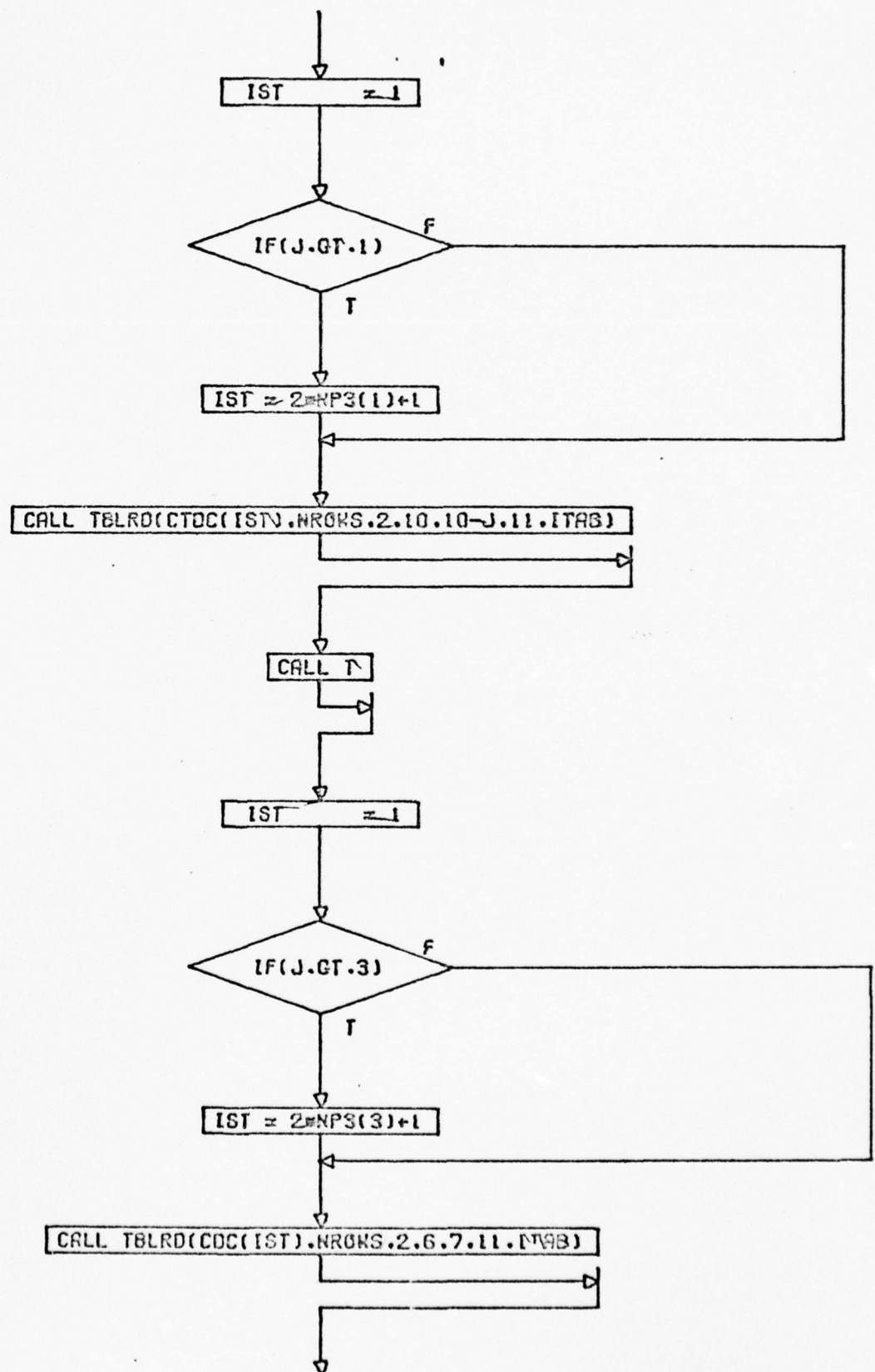
CONT. ON PG 2.



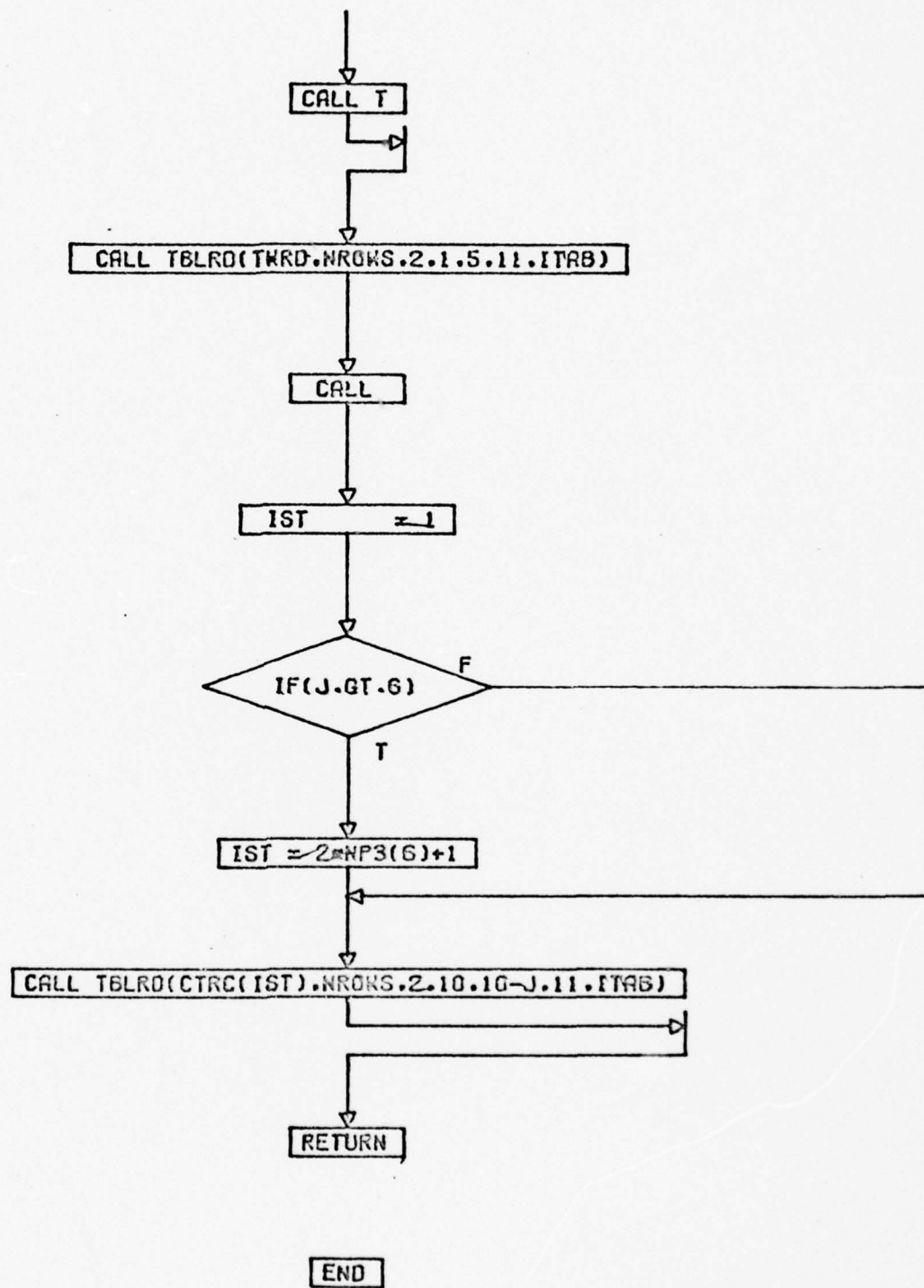


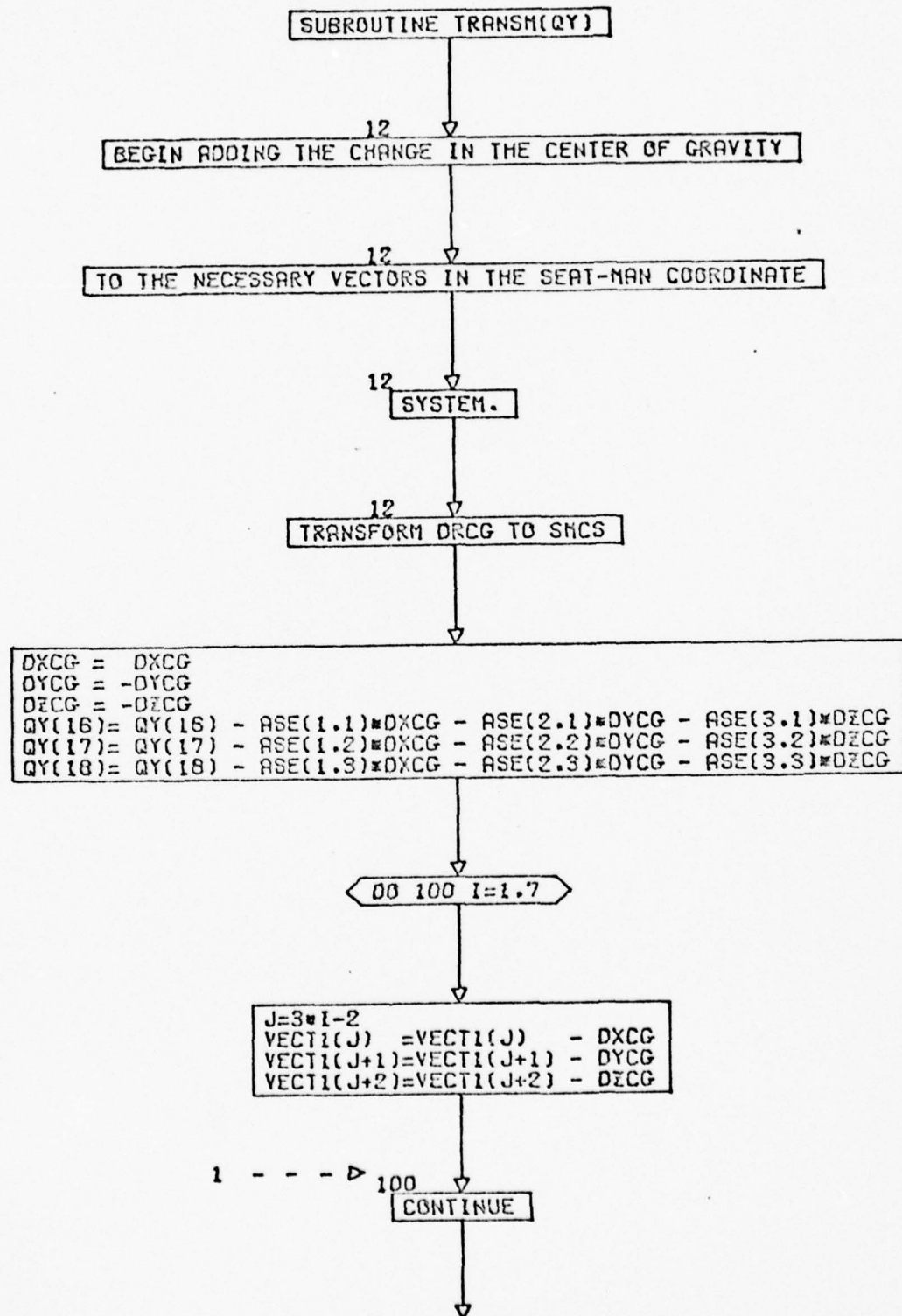


CONT. ON PG 4

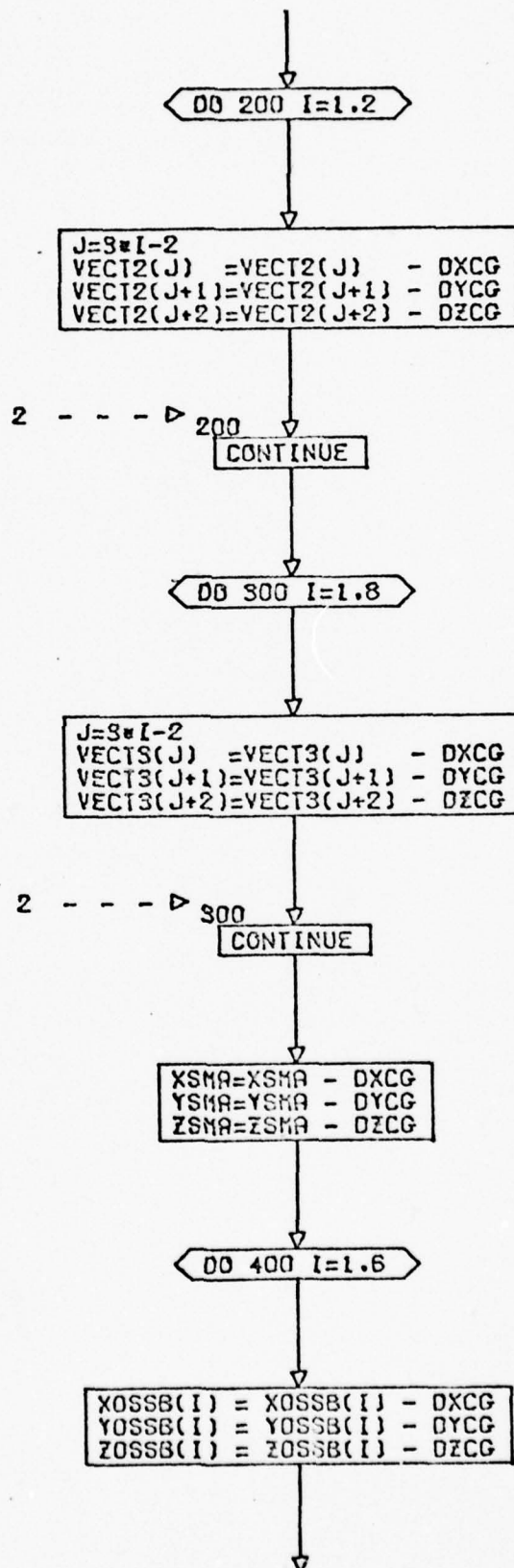


CONT. ON P0 5

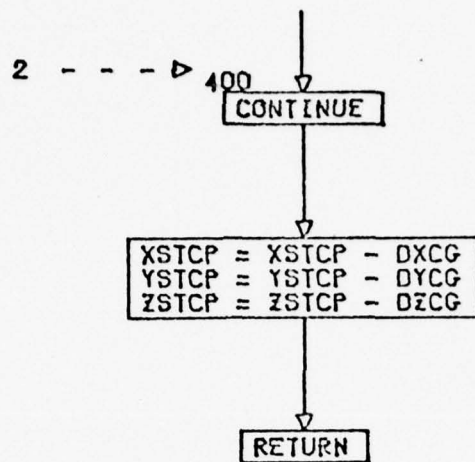




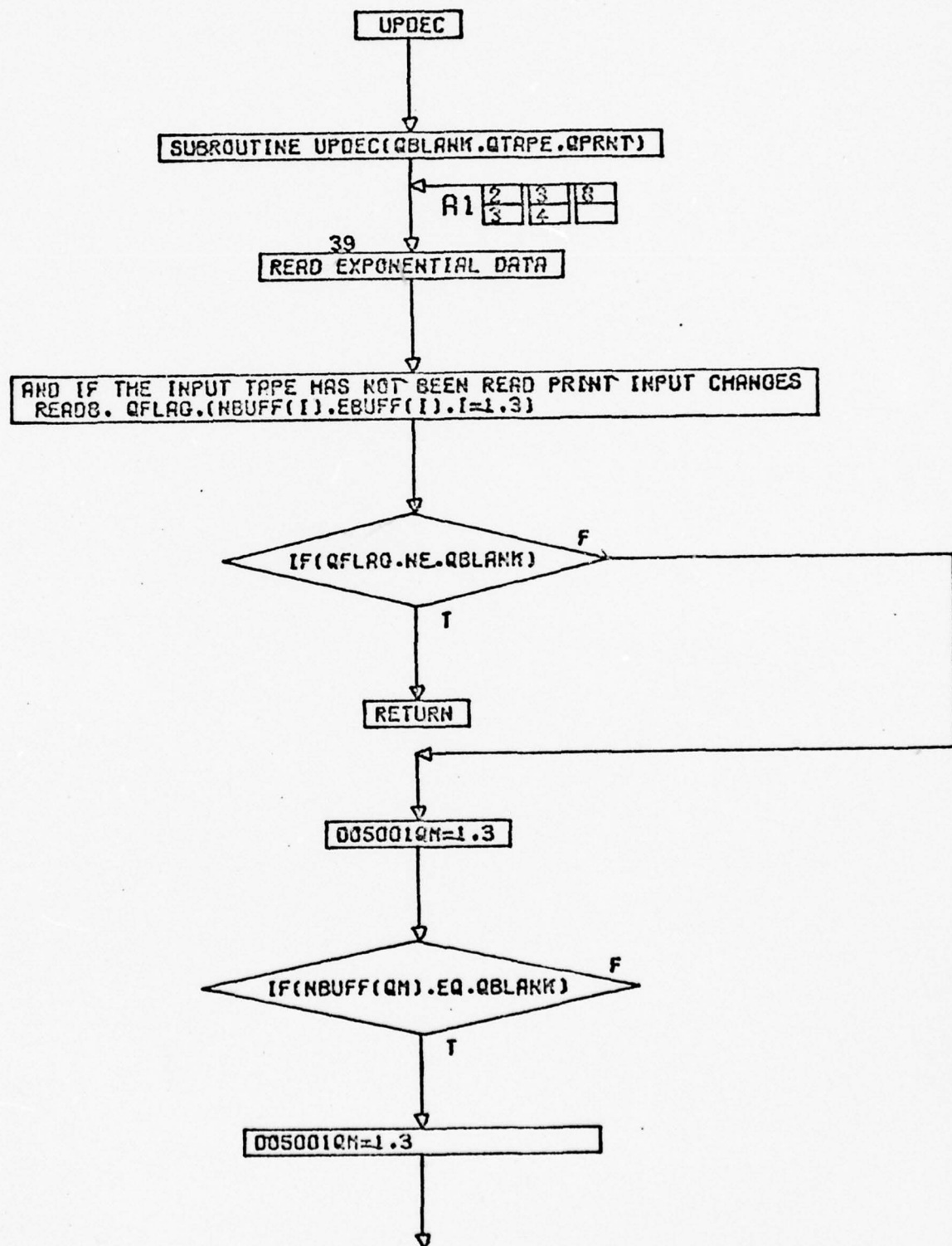


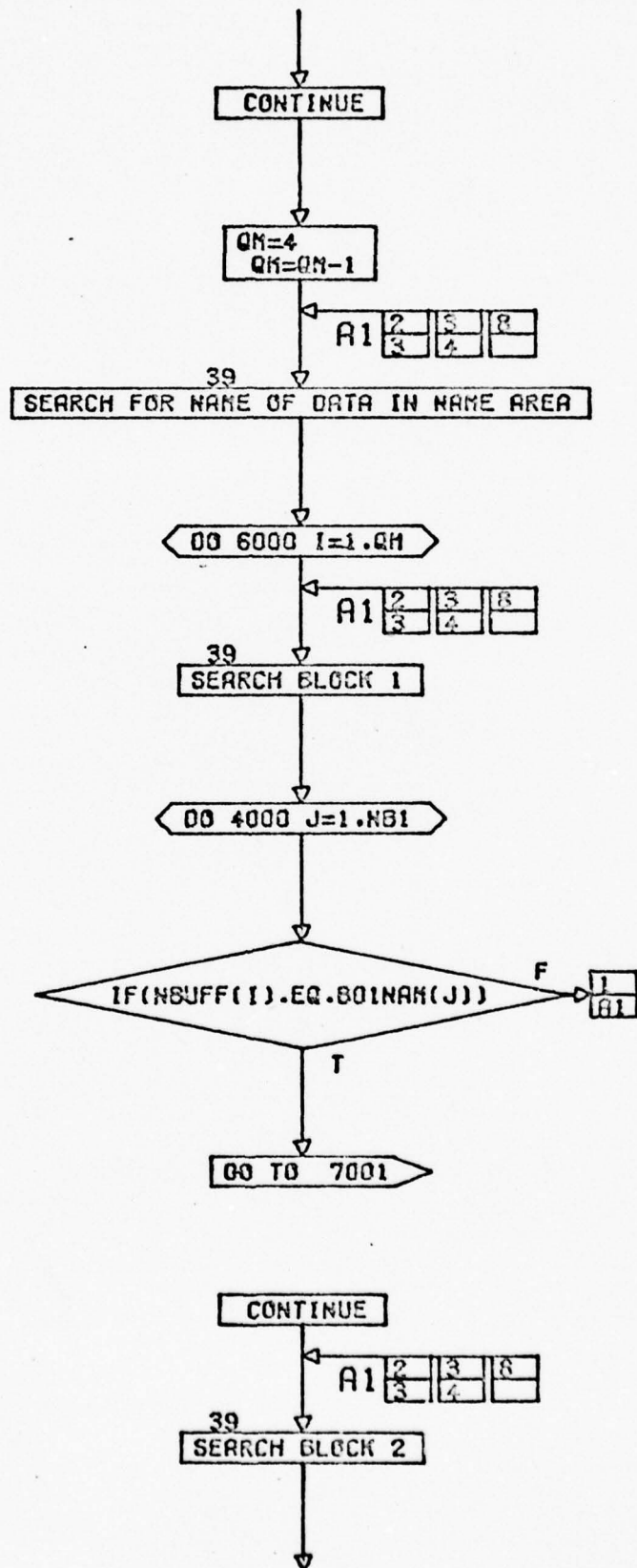


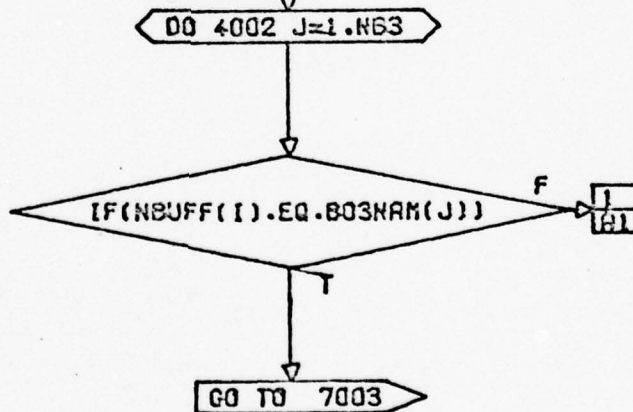
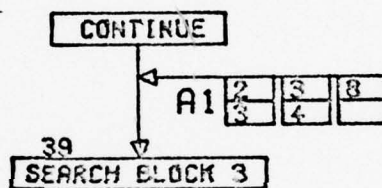
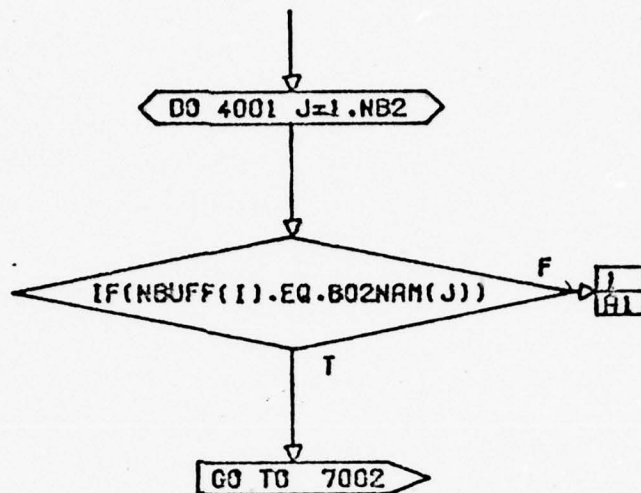
CONT. ON PG 3



END



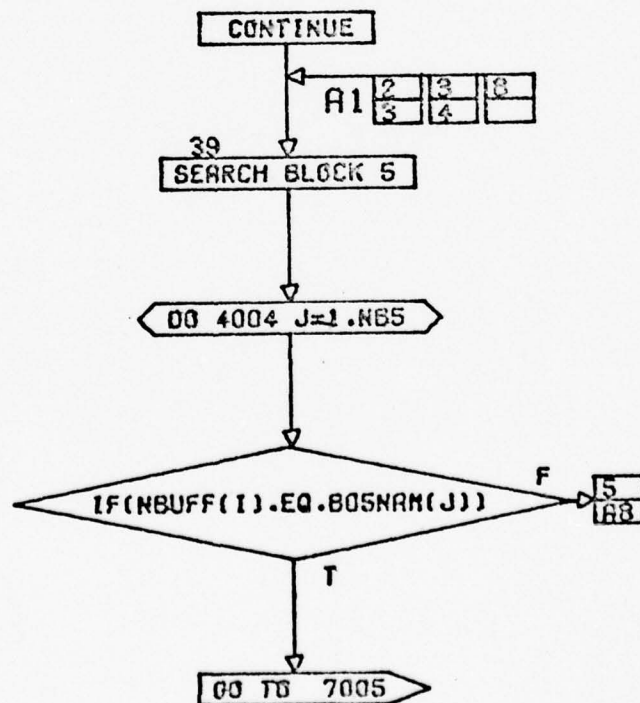
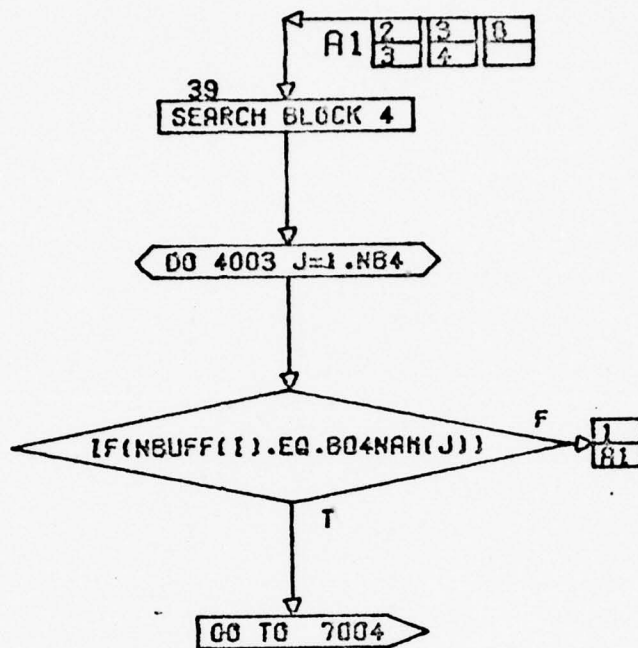


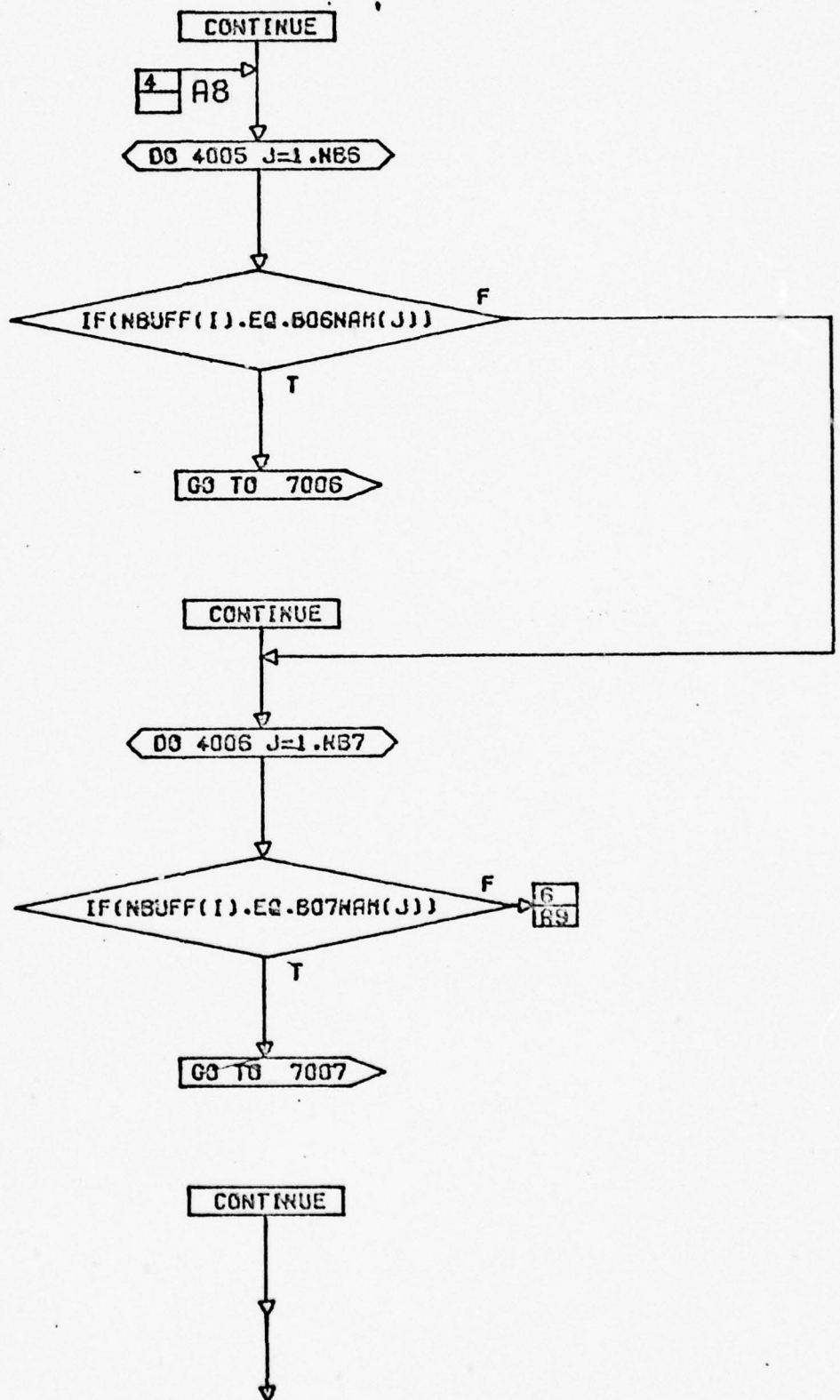


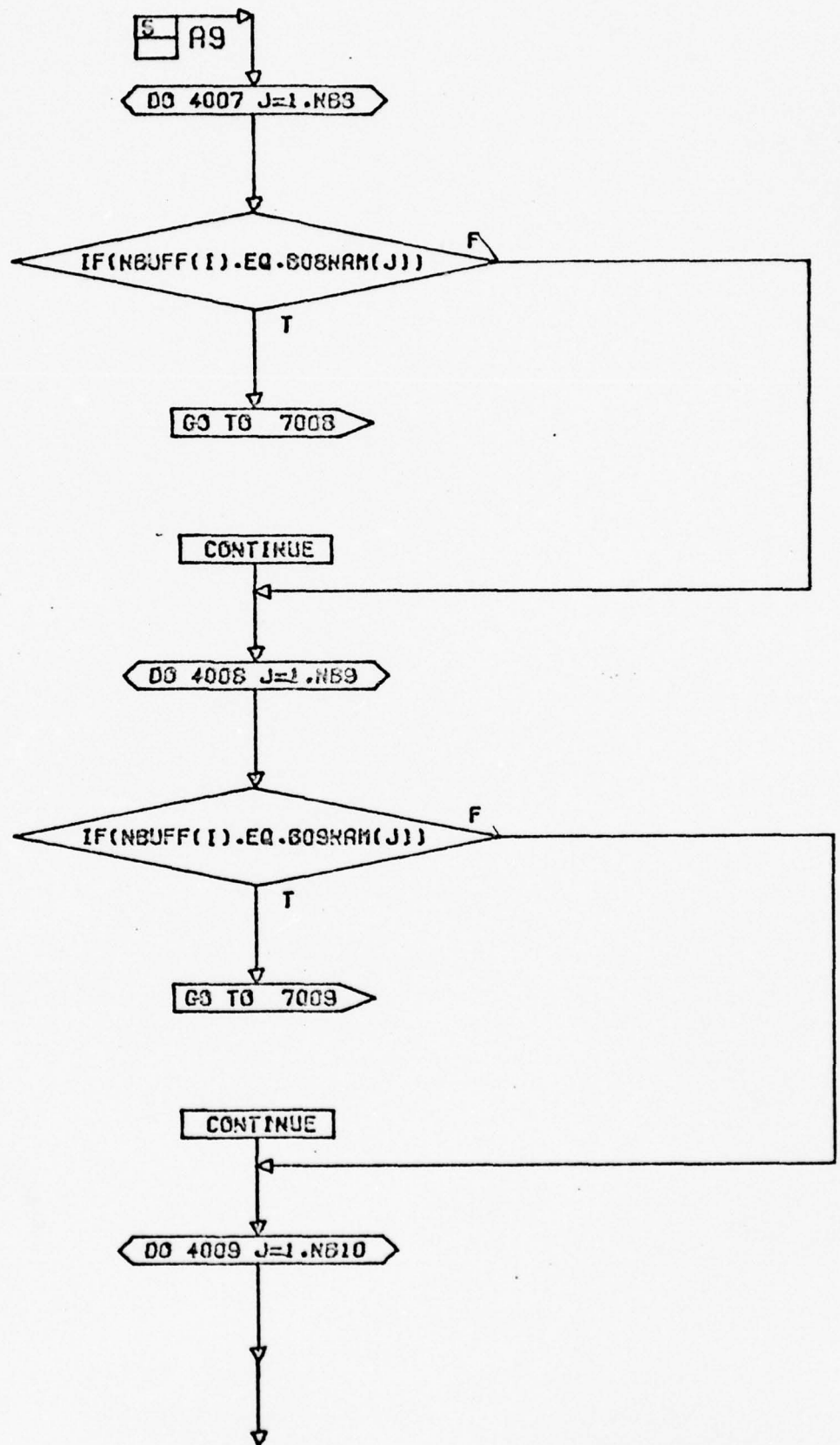
CONTINUE

CONT. ON P0 4

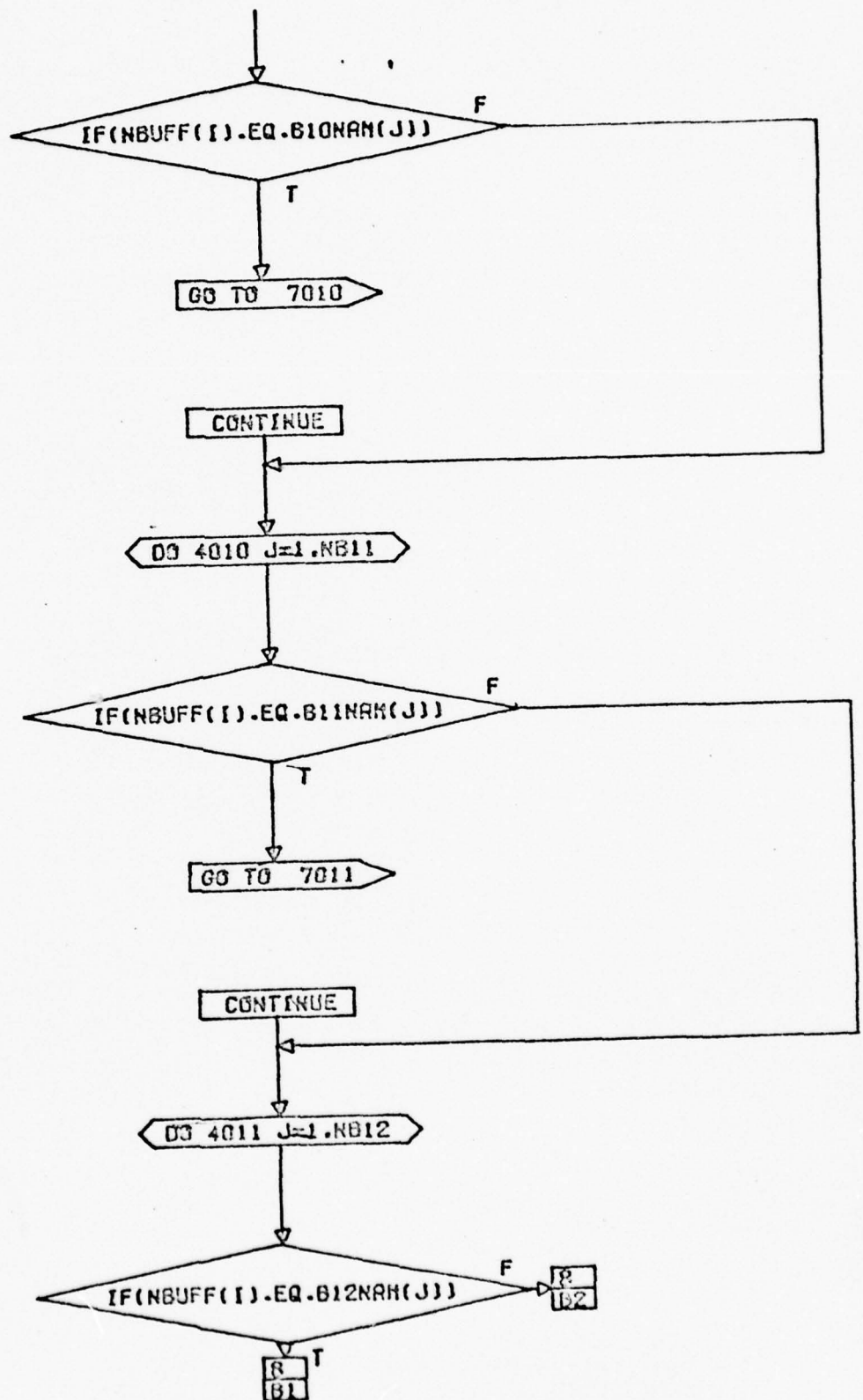


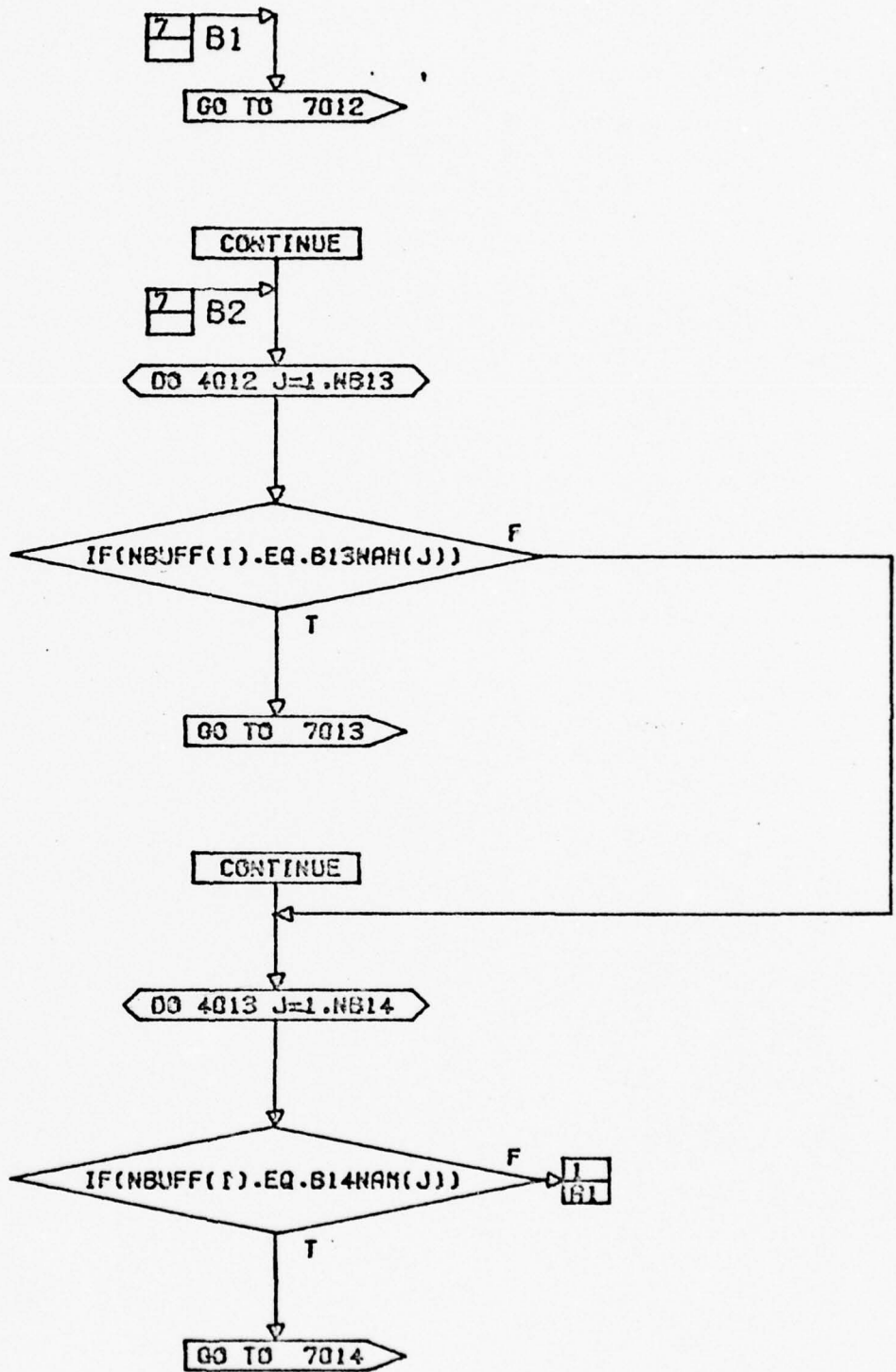




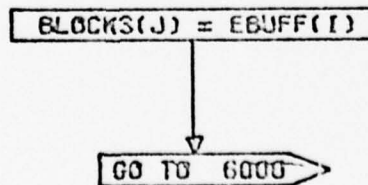
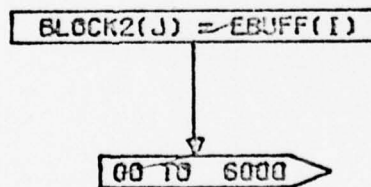
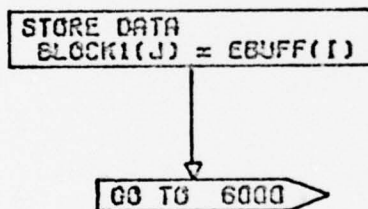
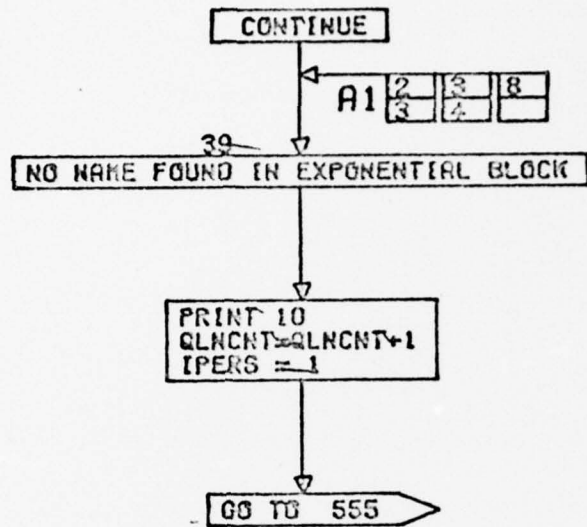


CONT. ON PG 7









BLOCK4(J) = EBUFF(I)

GO TO 6000

BLOCK5(J) = EBUFF(I)

GO TO 6000

BLOCK6(J) = EBUFF(I)

GO TO 6000

BLOCK7(J) = EBUFF(I)

GO TO 6000

BLOCK8(J) = EBUFF(I)

GO TO 6000

BLOCK9(J) = EBUFF(I)

GO TO 6000

BLOCK10(J) = EBUFF(I)

GO TO 6000

BLOCK11(J) = EBUFF(I)

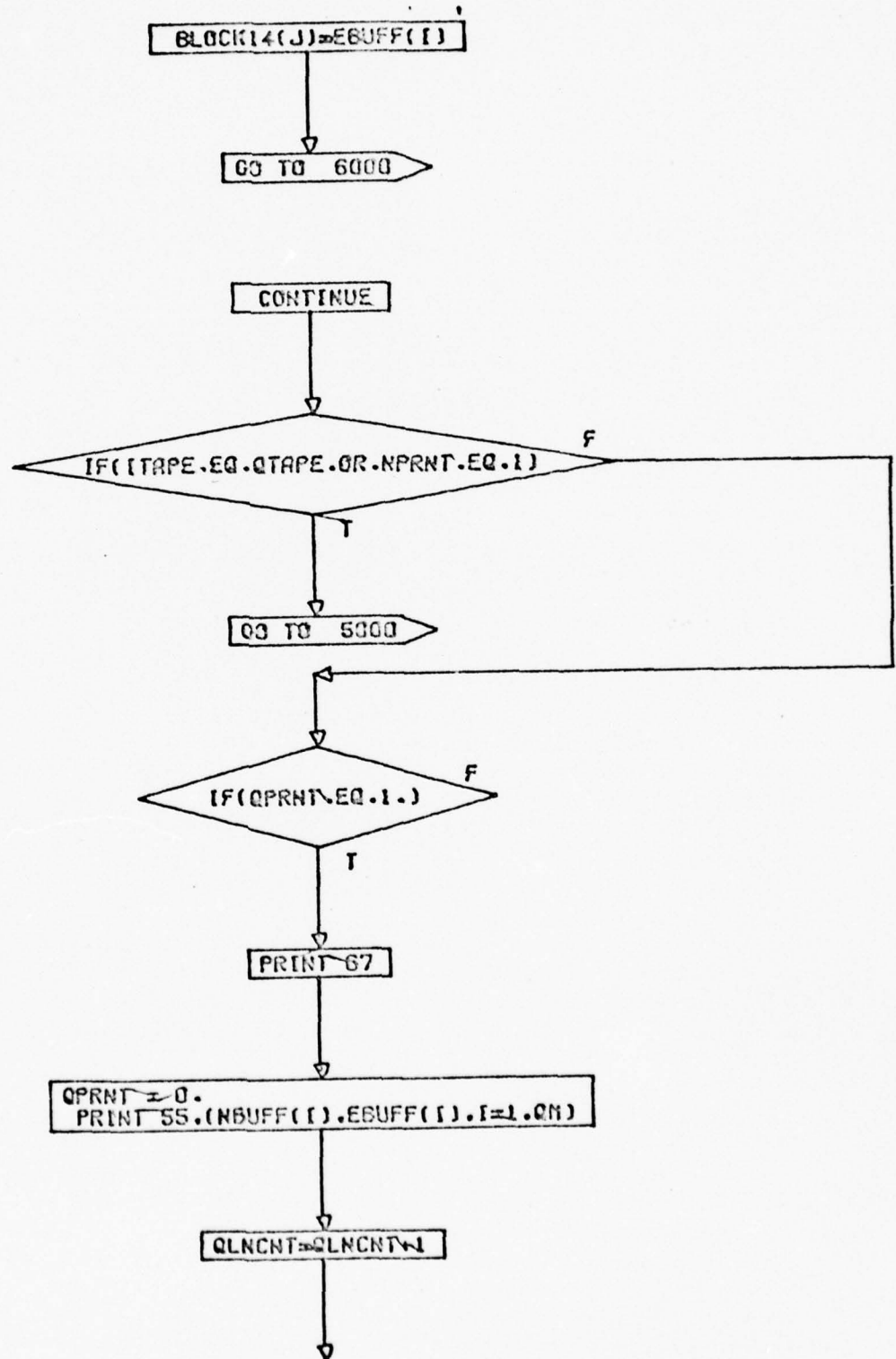
GO TO 6000

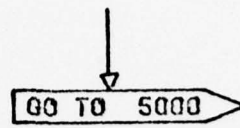
BLOCK12(J) = EBUFF(I)

GO TO 6000

BLOCK13(J) = EBUFF(I)

GO TO 6000





END



#### REFERENCES

1.   NWL Technical Report Number TR-3098, February, 1974,  
titled: 'Air Crew Automated Escape System Simulation Model.'
2.   NWL Technical Note TN-K7-7/74, February 1974, titled:  
'Program Maintenance Manual for ICARUS a Computer Program to  
Simulate Escape Systems.'

APPENDIX A

DYNAMIC RESPONSE INDEX (DRI) EQUATIONS

## DYNAMIC RESPONSE INDEX (DRI) EQUATIONS

The following spring damper equation is utilized in calculating the dynamic response index (DRI), a measure of the compressibility of the pilot's spine:

1.  $\ddot{Y} + c\dot{Y} + kY = A_y$

Where:  $c$  = damping coefficient (/sec)  
 $k$  = stiffness constant (lbs/in)  
 $A_y$  = vertical acceleration (ins/sec<sup>2</sup>)  
 $Y$  = displacement in inches

2.  $DRI = (\omega_n^2/g) Y$

Where:  $\omega_n^2 = k/m$   
 $m$  = mass of seat/man combination (lbs-sec<sup>2</sup>/in)  
 $\omega_n^2$  = natural freq (rad/sec)  
 $g$  = acceleration due to gravity (in/sec<sup>2</sup>)

The above equation (1) is numerically integrated and the DRI is calculated using the displacement obtained at each time step of the ejection trajectory.

APPENDIX B

DYNAMIC CENTER OF GRAVITY EQUATIONS

## DYNAMIC CENTER OF GRAVITY EQUATIONS

The displacement of the pilot's center of gravity from its static position has been modelled using 3 independent spring-damper equations, one for each axis of motion.

1. Along the x-axis of motion

$$\ddot{X} + c_x \dot{X} + F(x) = A_x$$

$$A_x = F_x/M$$

Where:  $F_x$  = impressed force along the x-axis (lbs)

$M$  = mass of seat/man combination (lbs-sec<sup>2</sup>/ft)

$A_x$  = acceleration of seat/man along the x-axis (ft/sec<sup>2</sup>)

$c_x$  = damping constant (/sec)

$F(x)$  = elastic acceleration (ft/sec<sup>2</sup>)

$F(x)$  subject to the following constraints:

$$x < 0, F(x) = k_n(x)$$

$$0 \leq x \leq x_{\text{slack}}, F(x) = 0$$

$$x > x_{\text{slack}}, F(x) = k_p(x - x_{\text{slack}})$$

Where:  $x$  = displacement along the x-axis (ft)

$x_{\text{slack}}$  = slack constant along the x-axis (ft)

$k_n, k_p$  = spring modulus constants (/sec<sup>2</sup>)

2. Along the y-axis of motion

$$\ddot{Y} + c_y \dot{Y} + s_y Y = A_y$$

$$A_y = F_y/M$$

Where:  $F_y$  = impressed force acting on the seat/man combination along the y-axis (lbs)

$M$  = mass of seat/man (lbs/sec<sup>2</sup>/ft)



$A_y$  = acceleration of seat/man along the y-axis (ft/sec<sup>2</sup>)

$c_y$  = damping constant (/sec)

$s_y$  = spring modulus constant (/sec<sup>2</sup>)

3. Along the z-axis of motion

$$\ddot{Z} + c_z \dot{Z} = F(z) = A_z$$

$$A_z = F_z/M$$

Where:  $F_z$  = impressed force acting on the seat/man combination along the z-axis (lbs)

$M$  = mass of seat/man (lbs-sec<sup>2</sup>/ft)

$A_z$  = acceleration of seat/man along the y-axis (ft/sec<sup>2</sup>)

$c_z$  = damping constant (/sec)

$F(z)$  subject to the following constraints:

$$Z < Z_{BOT}, \quad F(Z) = S_{ZN2} * (Z - Z_{BOT}) + S_{ZN1} * (Z_{BOT})$$

$$Z_{BOT} < Z < 0, \quad F(Z) = S_{ZN1} * Z$$

$$0 \leq Z \leq SLACK, \quad F(Z) = 0$$

$$ZSLACK < Z, \quad F(Z) = S_{ZP} * (Z - ZSLACK)$$

Where:  $Z$  = displacement along the z-axis (ft)

$Z_{BOT}$  = bottoming distance in the (-)  $Z$  direction (ft)

$ZSLACK$  = slack distance in (+)  $Z$  direction (ft)

$S_{ZN1}$ ,  $S_{ZN2}$ ,  $S_{ZP}$  = spring modulus constants (/sec<sup>2</sup>)

APPENDIX C

MARTIN-BAKER CATAPULT EQUATIONS

## MARTIN-BAKER CATAPULT EQUATIONS

The following linear spring-damper and tube bending equations are used to simulate the Martin-Baker catapult system.

### 1. Rail/Slipper Interaction

There are six slippers attached to the seat, three on each side of the seat, starting at the bottom of the seat (right hand side) - slippers 1, 2, and 3, (on the left hand side) - slippers 4, 5, and 6. During the catapult phase of the trajectory, the right and left slippers move up and off the right and left rails (respectively) of the catapult (tube 3). The following spring-damper equations are used to arrive at the forces and moments acting on the seat/man during this segment of the catapult phase:

If  $Y_{\text{slip}_i} > \text{RAILNT}$  then  $F_{\text{sx}_i}, F_{\text{sz}_i}, F_{\text{sy}_i}, M_{\text{sx}_i}, M_{\text{sz}_i}, M_{\text{sy}_i} = 0$

otherwise  $F_{\text{csx}_i} = k_s \Delta x_i + c_s \dot{\Delta x}_i$

$F_{\text{csz}_i} = k_s \Delta z_i + c_s \dot{\Delta z}_i$

$F_{\text{csy}_i} = \mu_s (F_{\text{x}_i}^2 + F_{\text{z}_i}^2)^{\frac{1}{2}}$

$$\begin{bmatrix} F_{\text{ssx}_i} \\ F_{\text{ssy}_i} \\ F_{\text{ssz}_i} \end{bmatrix} = \text{DSC} \begin{bmatrix} F_{\text{csx}_i} \\ F_{\text{csy}_i} \\ F_{\text{csz}_i} \end{bmatrix}$$

Where DSC is the rotation from the catapult (CCS) the seat/man coordinate system (SMCS)

$$\begin{bmatrix} L_{\text{ss}_i} \\ M_{\text{ss}_i} \\ N_{\text{ss}_i} \end{bmatrix} = \begin{bmatrix} X_{\text{sscg}_i} \\ Y_{\text{sscg}_i} \\ Z_{\text{sscg}_i} \end{bmatrix} \times \begin{bmatrix} F_{\text{ssx}_i} \\ F_{\text{ssy}_i} \\ F_{\text{ssz}_i} \end{bmatrix}$$

Torque due to the torsional spring-damper equations acting in the pitch plane.

$$\text{TORPTCH} = k_{\text{TOR}} \Delta \theta + c_{\text{TOR}} \dot{\Delta \theta}$$

Where:  $k_s$  = slipper spring modules constant (lbs/ft)

$c_s$  = slipper damping constant (lbs-sec/ft)

$\mu_s$  = slipper coefficient of friction

$\Delta x_i$  = displacement of  $i^{\text{th}}$  slipper (CCS) from the rail in the x-direction (ft)

$\Delta y_i$  = displacement of  $i^{\text{th}}$  slipper (CCS) from the rail in the y-direction (upward) (ft)

$\Delta z_i$  = displacement of  $i^{\text{th}}$  slipper (CCS) from the rail in the z-direction (ft)

$F_{csx_i}, F_{csy_i}, F_{csz_i}$  = forces in x, y, and z-direction (lbs) in CCS due to rail/slipper interaction

$X_{sscg_i}, Y_{sscg_i}, Z_{sscg_i}$  = distance from slipper<sub>i</sub> to seat/man center of gravity, x, y, and z directions (SMCS) respectively (ft)

$L_{ssx_i}, M_{ssx_i}, N_{ssx_i}$  = moments produced by the rail/slipper interaction around the seat/man center of gravity (SMCS) (ft-lbs)

$k_{\text{TOR}}$  = torsional spring modules constant (lbs/ft)

$c_{\text{TOR}}$  = torsional damping constant (lbs-sec/ft)

$\Delta \theta$  = angle between rails and seat back (rad)

$\dot{\Delta \theta}$  = angular velocity of  $\Delta \theta$  (rad/sec)

The following tube extension equations are used to arrive at the forces and moments acting on the seat/man during the catapult phase of the trajectory.

Tube extension - vector from top of tube 3 to top of telescoping tubes 2 and 1 (tube 2 contained inside tube 3, tube 1 contained inside tube 2 at start of

catapult phase). Tube 2 starts moving up and out of tube 3. When the maximum length of tube 2 is reached then tube 1 starts moving up and out of tube 2.

$$TUBEXT = [X_{cctep}^2 + (Y_{cctep} - TUBLTH3)^2 + Z_{cctep}^2] \quad (CCS)$$

If  $TUBEXT > TUBLTH1 + TUBLTH2$  set all forces and moments acting on seat/man due to the catapult equal to zero.

Otherwise, compute forces and moments acting on seat/man due to the tube bending as follows:

Compute Deflection of tube in X-Z plane (CCS)

$$DEFSL = (X_{cctep}^2 + Z_{cctep}^2)$$

$$0 \leq TUBEXT \leq 2$$

$$F_{TUBE} = k_s \cdot DEFSL + c_s \cdot \dot{DEFSL}$$

$$\theta_{AB} = (F_{TUBE} \cdot TUBEXT^2) / (2 \cdot E \cdot (I_1 + I_2))$$

$$2 < TUBEXT \leq TUBLTH1$$

$$F_{TUBE} = [3 \cdot DEFSL \cdot E \cdot (I_1 + I_2)] / TUBEXT^3$$

$$\theta_{AB} = [F_{TUBE} \cdot TUBEXT^2] / [2 \cdot E \cdot (I_1 + I_2)]$$

$$TUBLTH1 < TUBEXT \leq TUBLTH2$$

$$F_{TUBE} = (3 \cdot DEFSL \cdot E) / [(TUBEXT - TUBLTH1)^3 / I_1 + (TUBLTH1)^3 / (I_1 + I_2)]$$

$$\theta_{AB} = [F_{TUBE} / (2E)] [(TUBEXT - TUBLTH1)^2 / I_1 + TUBLTH1^2 / (I_1 + I_2)]$$

$$TUBLTH2 < TUBEXT \leq TUBLTH1 + TUBLTH2$$

$$F_{TUBE} = (3 \cdot DEFSL \cdot E \cdot LMOD) / [(TUBEXT - TUBLTH2)^3 / I_1 + (TUBLTH1 + TUBLTH2 - TUBEXT)^3 / (I_1 + I_2) + (TUBEXT - TUBLTH1)^3 / I_2]$$

$$\theta_{AB} = (F_{TUBE} \cdot [(TUBEXT - TUBLTH2)^2 / I_1 + (TUBLTH1 + TUBLTH2 - TUBEXT)^2 / (I_1 + I_2) + (TUBEXT - TUBLTH1)^2 / I_2])$$



$$F_{xtube} = - F_{tube} * X_{cctep} / DEFSL$$

$$F_{ztube} = - F_{tube} * Z_{cctep} / DEFSL$$

$$F_{ytube} = - UM_{tube} * F_{tube}$$

$$\begin{bmatrix} F_{sxtube} \\ F_{sytube} \\ F_{sztube} \end{bmatrix} = DSC \begin{bmatrix} F_{xtube} \\ F_{ztube} \\ F_{ytube} \end{bmatrix} \quad (CCS \longrightarrow SMCS)$$

$$\begin{bmatrix} L_{tube} \\ M_{tube} \\ N_{tube} \end{bmatrix} = \begin{bmatrix} X_{step} \\ Y_{step} \\ Z_{step} \end{bmatrix} \times \begin{bmatrix} F_{sxtube} \\ F_{sytube} \\ F_{sztube} \end{bmatrix} \quad (SMCS)$$

Moments due to torsional spring-damper equations at the tube attachment point acting in the pitch, roll and yaw directions:

$$yaw = K_{ytube} * \Delta\psi + C_{ytube} * \dot{\Delta\psi}$$

$$ptch = K_{ptube} * \Delta\theta + C_{ptube} * \dot{\Delta\theta}$$

$$roll = K_{rtube} * \Delta\phi + C_{rtube} * \dot{\Delta\phi}$$

Total forces due to the catapult:

$$F_{xcat} = \sum_{i=1}^6 F_{ssxi} + F_{sxtube}$$

$$F_{ycat} = \sum_{i=1}^6 F_{ssyi} + F_{sytube}$$

$$F_{zcat} = \sum_{i=1}^6 F_{sszi} + F_{sztube}$$

Total moments due to the catapult:

$$L_{cat} = \sum_{i=1}^6 L_{ssi} + L_{tube} + YAW$$

$$M_{cat} = \sum_{i=1}^6 M_{ssi} + M_{tube} + PTCH$$

$$N_{cat} = \sum_{i=1}^6 N_{ssi} + N_{tube} + ROLL$$

Where: TUBEXT = is the vector (in feet) from the top of catapult tube 3 to the top of the telescoping tubes 2 and 1 (CCS).

TUBELTH1, 2 and 3 = lengths, in feet, of catapult tubes 1, 2 and 3.

$X_{cctcp}$ ,  $Y_{cctcp}$  and  $Z_{cctcp}$  = coordinates (CCS) of the extending tubes 2 and 1 in feet.

DEFSL = the deflection, in feet, of the extending tubes 1 and 2, from the catapult initial position in the x-z plane, CCS.

DEFSL = rate of change of DEFSL in ft/sec (CCS).

FTUBE = resultant force in lbs, acting on the seat/man due to the tube bending (CCS).

$UM_{tube}$  = tube bending friction coefficient.

$F_{xtube}$ ,  $F_{ytube}$  and  $F_{ztube}$  = components of the tube bending force (lbs) along the x, y and z directions (CCS).

$F_{sxtube}$ ,  $F_{sytube}$  and  $F_{sztube}$  = components of the tube bending force (lbs) along the x, y and z directions (SMCS).

$\theta_{AB}$  = angle between tangent to the tube end and vertical axis (Y) of  
of the CCS, radians.

E = elasticity modulus of tubes 1, 2 and 3, (lbs/ft<sup>2</sup>).

$$I_1 = \frac{\pi}{64} (D_{10}^4 - D_{1i}^4)$$

$$I_1 = \frac{\pi}{64} (D_{20}^4 - D_{2i}^4)$$

D<sub>10</sub>, D<sub>20</sub> outside diameters of tubes 1 and 2

D<sub>1i</sub>, D<sub>2i</sub> inside diameters of tubes 1 and 2  
(ft<sup>4</sup>).

X<sub>step</sub>, Y<sub>step</sub> and Z<sub>step</sub> = coordinates, in ft, of seat contact point with  
telescoping tubes (SMCS).

L<sub>tube</sub>, M<sub>tube</sub>, N<sub>tube</sub> = moments produced by the tube bending, around the  
seat/man center of gravity (SMCS) ft-lbs.

K<sub>y<sub>tube</sub></sub>, K<sub>p<sub>tube</sub></sub>, K<sub>r<sub>tube</sub></sub> = tube attachment torsional spring modulus con-  
stants, ft-lbs/rad, in the yaw, pitch and roll  
directions respectively.

C<sub>y<sub>tube</sub></sub>, C<sub>p<sub>tube</sub></sub>, C<sub>r<sub>tube</sub></sub> = tube attachment torsional spring-damper con-  
stants, ft-lbs-sec/rad, in the yaw, pitch and  
roll directions respectively.

$\Delta\psi, \Delta\theta, \Delta\phi$  = angular displacements (rad), of the seat back relative to  
the catapult tube in the yaw, pitch and roll directions.

$\dot{\Delta\psi}, \dot{\Delta\theta}, \dot{\Delta\phi}$  = rate of change of the  $\Delta\psi, \Delta\theta, \Delta\phi$  (rad/sec).

$F_{xcat}$ ,  $F_{ycat}$ ,  $F_{zcat}$  = total forces (lbs) acting on the seat/man due to the catapult, SMCS.

$L_{cat}$ ,  $M_{cat}$ ,  $N_{cat}$  = total moments (ft-lbs) produced by the catapult around the seat/man center of gravity (SMCS).